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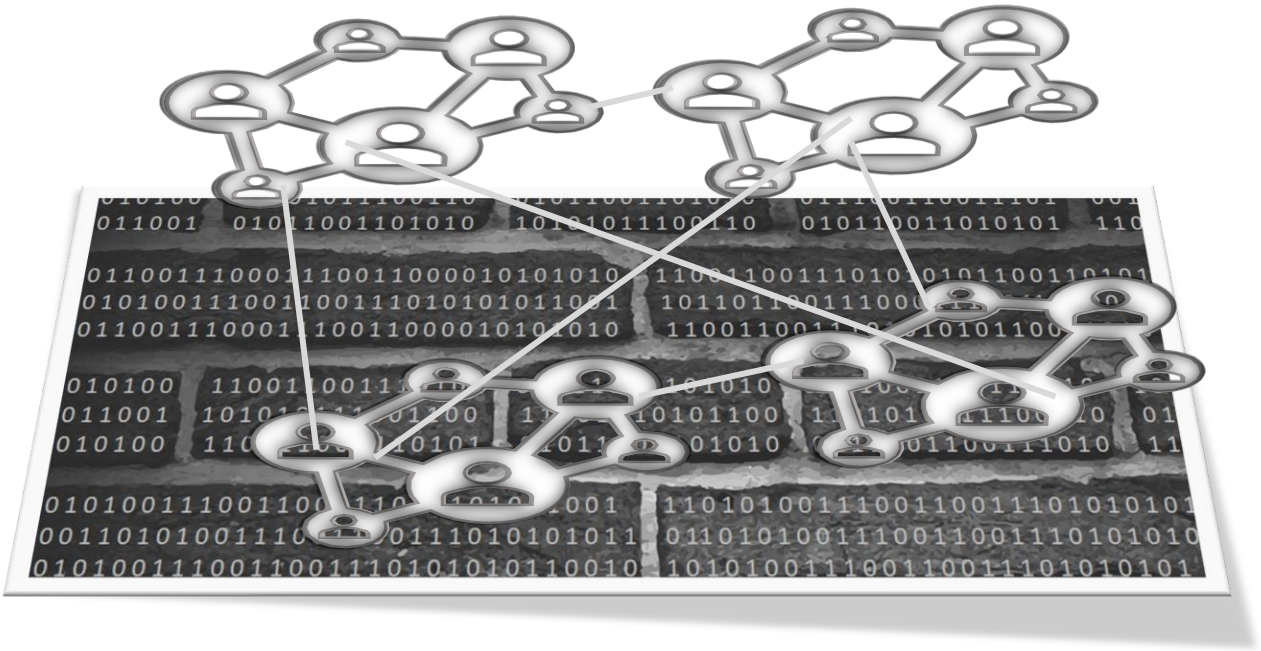
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EXPLORING LEARNING FOR WORK IN THE CONTEXT OF DIGITAL WORK TECHNOLOGIES

THE SOCIOMATERIAL CASE OF ENGINEERING PROFESSIONALS IN THE CONSTRUCTION INDUSTRY



By MARLOES DE MUNNIK

A THESIS submitted to the Faculty of Humanities, University of the Witwatersrand,
in fulfilment of the requirements for the degree of Doctor of Philosophy
in the Department of Education, at the Centre for Researching Education and Labour

Supervisor: Prof Stephanie Matseleng-Allais
Co-Supervisor: Dr Reuben Dlamini

Johannesburg, South Africa

September 2020

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DECLARATION PAGE

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September 2020



ABSTRACT

Title: EXPLORING LEARNING FOR WORK IN THE CONTEXT OF DIGITAL WORK TECHNOLOGIES: THE SOCIOMATERIAL CASE OF ENGINEERING PROFESSIONALS IN THE CONSTRUCTION INDUSTRY

This thesis explores the relations between engineering professionals and their digital work context and relations to their learning for work practice. In the literature on workplace learning, the digital technology driver is argued to change and impact the work practice and learning of professionals. However, there is insufficient insight into the effects of digital technologies on professional responsibilities and learning, and little was known about the actual work practice of professionals. This has possible implications for how we think about professional learning.

This thesis shows that professional learning for daily *construction planning* and *project reporting* engineering work is understood as a continuous effect of the *performing* of heterogeneous *actors*. The human and non-human *actors* perform themselves into professional action. Altogether contributing to and shaping the *construction planning* and *project reporting* work practices. Wherefore the human *actors* need the ability to *enact* upon other *actors* in the work practice for which skills and knowledge resides in the individual professional and in the practice. Learning moves beyond something that can be detached from its context or exist in a final form in individuals.

It corroborates theoretical understandings from other research in engineering that learning opportunities arise when new mediating *actors* are part of the practice, and extends this and adds, that the learning opportunities develop when sociomaterial *actors* perform themselves significantly into action in the work practice and change the work practice. Understanding the learning for professional *construction planning* and *project reporting* engineering work practices in relation to human-digital interactions may be termed as a unique sociomaterial networked relative stability. The term unique since each network is specific to the practice and to the *actors* taking part and therefore learning varies. Sociomaterial since both human and material *actors* shape and define the practice and learning. Since the *unique sociomaterial relative stability* of the network of the two daily engineering work practices of *construction planning* and *project reporting*, stabilised and set educational curriculum are increasingly challenged and thus a relative stability. Participation in real professional engineering work practice is modestly suggested to cater for this understanding about learning for professional practice.

The study was done by conducting a mixed-methods explorative sequential case-study among a small selection of engineering professionals working in the construction industry coming from three countries across the globe. The case study, drawing on sociomaterial approaches (Practice-Theory and *Actor* Network Theory), provided the exploration into the three research areas of concern: work, skills, and learning. This was done sociomaterial through identifying the *performing* of each *actor* and their connections to other constructs in the practice (tracing) seen from the practitioner view.

Survey analysis showed that the one size does not fit all in the two work practices of *construction planning* and *project reporting* applied to: the perceived intensity of work changes related to digital

work technologies, the individual skills and knowledge required to be an active member of the practice, and to the learning for these individual requirements. The one size does not fit all was based on the different professional levels and different work locations.

The continued analysis of the two selected work practices of the *construction planning* and *project reporting work practices* revealed that most of the professionals in this study experienced significant changes in the professional responsibilities that they previously fulfilled and were now shared with digital technologies but varied in increased complexity and decreased complexity of their core daily engineering work practice and skill demands. This was predominantly as a result of the basic and advanced reasoning *performing* of digital technologies such as those from Simulations and Big Data. Emerging from these insights was that the concept of a unique sociomaterial network appeared relevant for the engineering professionals' *construction planning* and *project reporting* work practices.

Beyond individual professional capabilities, those emerging in practice and *enact*ed between different *actors* of the core practices were relevant to reach the common goal or outcome of the work practice for each engineering professional and the practice was then understood as a unique sociomaterial networked relative stability since the stability could change and was relative to the *performing* of heterogenous others.

The relations with the learning of the professionals was that learning happened through experience in practice, through the *performing* into professional action, through interactions and coordination with other *actors*, complemented with a diverse professional knowledge base to *enact* upon other *actors* such as digital technologies in their work. Learning mechanisms such as learning by trying and using intuition were common to practice the know-how of their work and learning during schooling was found to develop the individual knowledge foundation that had preceded their work. Learning was thus understood to be residing in the individual engineering professional and in the selected core work practices of *construction planning* and *project reporting* and changed in the light of these practices. However, a stronger relative stability was found in learning from others and work experience while the academic knowledge base was acknowledged being important before transferring to work.

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This PhD program's journey has been one that I will never forget. When listening to celebratory speakers who had successfully completed the journey, I could never imagine how the journey would affect me personally. This journey has been one with many highs and lows but most significantly, it has changed me as a person in my whole being and way of thinking.

Given the fact that this road is full of hurdles to overcome and that it creates major learning curves for the one who embarks on it, the journey could have never been possible without the dedicated help of my main supervisor. Prof Stephanie Matseleng-Allais has taken on the job of consistently commenting on and challenging my work. Although this required some adaptation from my side at the start of our journey together, her input and meticulous examination of my writing and arguments helped me to progress in my work and ensured a steady progression of quality. One does not imagine initially how important it is to have a supervisor who is detailed in comments and feedback, but I learned the value of this later in my programme. Therefore, I would like to thank her for her major contribution to my development and for challenging my ways of thinking and writing to become an aspiring researcher in the social science field.

Dr Reuben Dlamini was my co-supervisor and advised on the procedural and organisational part of the research when needed. In the early days, he was also supportive and provided clarifications from a social science perspective and translated them into a natural science perspective so that I could grasp them. This helped to change my thinking and understanding of social science on the way.

The data could have never been collected without the help of the participating organisations and their employees. I collected 41 completed surveys and conducted 7 successful interviews with engineering professionals working in the construction industry. These professionals and their management took the time to respond to my questions and contributed a portion of their working time to do this. To all who contributed to the actual data collection, either by approving, giving feedback on the tools that were used, or completing the surveys and interviews, thank you so much for your valuable contribution. I am grateful for your support and without you, this work could have never been completed.

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My occasional work as an Expo2020 volunteer helped me through the times when I thought that there was no other existence apart from my PhD. The Expo house of volunteers' team was always interested in my progress and my colleagues from the interview team provided the occasional social support. The 'shut up and write' sessions idea that I copied from my supervisor and started in Dubai with two PhD peers from other universities halfway through the program helped to provide focused writing sessions.

On another note, the committee of the JVET organisation also proved important for my learning trajectory during the final stage of my PhD work. My conference article submission was accepted to be presented at the 13th JVET conference in Oxford in June 2019 and this opportunity to enabled to share my thoughts and research with other peers in the field helped me to define my final focus of my thesis. The workshop for early career researchers preceding the three-day conference helped me to write with a different technique which proved to be effective in some stages of the final thesis writing later on.

I would also like to express my gratitude to my colleagues and friends at the university and especially at the Researching Education and Labour Centre for their support, friendship and for giving me the feeling of belonging to their community even when I was only for the first half part of my program physically there. A special thanks to Sibu and Ndovhu for their friendship. The librarians from the education campus proved supportive in my program and became friends during the first stage of my study when I was still on campus and the contact remained over time.

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ABBREVIATIONS, AND A NOTE ON THE THESIS VOCABULARY/STYLE CONVENTIONS

The use of acronyms was avoid as much as possible in this thesis but the following have been used:

ANT *Actor*-Network Theory

WPL Work-Place Learning

This thesis uses a specific vocabulary that fits well with the use of sociomaterial sensibilities which will be elaborated on later in the thesis. The sociomaterial use, and in particular an ANT vocabulary has consequences for the specific word use. For example, *performing* used to refer to activities and doings, *actor* used to refer to a *performing* practice member, and *enactment* used to show. Although this thesis has adopted most 7th APA style guidelines, the decision was made to *italicize* important and possibly confusing terms such as those used in *Actor*-Network Theory, the two selected core engineering work practices and survey response options. In the thick interview descriptions in Chapter 7, the informants are referred to with *he* or *she*. Although not common in academic work, this way of describing is common in research with sociomaterial sensibilities and definite interpretations are not used.

CHAPTER 1 -INTRODUCTION, BACKGROUND AND RESEARCH PROBLEM

The story below captures what this thesis is about, and the remainder of the chapter further elaborates. The story is based on an engineering success story of a now famous structure that was once the entry for the World Expo in Paris in 1889. We are heading now towards the next World Expo that will take place in October 2020 in Dubai and one can only imagine how much has changed for engineering professionals since the one in Paris! Since 1932, innovations and automations, and especially the ones found in digital technologies, have shaped and impacted professional work.

> The Story of the Gustave Eiffel
>
> Gustave Eiffel, born 1832 in France, is the civil engineer that built the Eiffel Tower. Imagine, in an era where no computer was available, no mobile phone, no CAD and no laser measurement machine! Imagine the work tasks involved in this era, how much does it differ from the work tasks used now? Would Gustave Eiffel have used the same work process as what he did then? Would he need the same approaches and skills? Probably not, but we cannot test this issue with him. One thing we can assume is that technologies have contributed to change the way how we work, and it also might have changed the skills and knowledge building blocks used by professionals to do the work.
>
> Story informed with https://successstory.com/lists/most-famous-successful-engineers

Therefore, it is not surprising to have noticed that the focus in the upcoming World Expo is partially on opportunities of which a few of them were found in the digital technology innovation space[1].

1.1 Introduction

Times are changing, and experiences in the changing nature of work and technology are understood among many to be one of the main drivers. This perceived changing nature of work might impact professionals such as teachers and engineers. “Technology will not replace great teachers but technology in the hands of great teachers can be transformational” [2]. Although engineering professionals working in the construction industry rather than teachers are the focus of this thesis,

[1] Based on notes made during my work as an Expo2020 volunteer during the Expo2020 global innovation summit which took place in November 2019 in Dubai. The innovators of the 130 selected innovations from across the world were present during this three-day event.

[2] Twitter quote by Couros (2015). Extracted from https://twitter.com/gcouros/status/579129255797268480

the previous quote shows a positive view on professional work implications by focusing on complementing the professional in question. Therefore, the focus on engineering professionals working in a changing digital technology work context is key to this thesis. A more detailed discussion of why this was identified to be an interesting and significant focus for the current thesis is discussed in the following sections. In this chapter, I introduce the research that is central to this thesis, namely a topic in the field of learning for work in the context of changing digital technology. However, more importantly, the chapter defines the thesis research problem and shows why this was selected as a focus. In this section, I introduce, describe and justify why the thesis research problem was worth the investigation and I elaborate on the originality, significance and purpose of this thesis.

1.2 Background

The main focus of this thesis is the changing digital technological context in engineering work and the implications for professionals. This topic was considered relevant because the world of work was believed changing with digital technology use that have the potential to influence both the organisation and the human demands of the workplace (Colvin, 2015; Ford, 2015; International Labour Office, 2017; Schwab, 2016; Susskind & Susskind, 2017). The notion of changing skills and work practices became visible due to changes in the professional work-context, in this case, the digital technology work-context for engineering professionals working in the construction industry. Digital technologies such as simulations and big data were defined for this thesis as the 'tools and practices based on information and communication technology' which are used for work. While digital technologies such as laser scanners and mobile phones are easier to understand as 'tools', digital technologies as methods on the other hand, such as big data, simulations and virtual reality were more difficult to conceptualise and could be rather defined as a process. This is because the digital technologies as methods were not themselves the machines for operation but were rather programs and software that use other 'tools', such as computers, to execute their activity or *performing*.

Based on this perceived work digitalisation, the digital technology driver was believed to impact individual workers' work in the sense that it may change the way they practised their work, the individual and collective skills involved, and therefore professional development. "Digital technologies in combination with "big" data and predictive analytics are having a significant impact upon professional practices at individual, organisational, national and international levels" (Fenwick & Edwards, 2016, p. 117). At the individual level, professionals were believed to experience changes in their skill demands for distinct reasons. First, the professionals had to be able to conduct their possible changed work practices and work in the digital technology impacted work environment.

Second, skill implications were believed to arise because of the required skills that were directly associated with the ability to operate digital technologies. Finally, at the same time, digital technologies were also believed to impact other skills beyond those directly associated with operating digital technologies. See for an elaborated exploration, Sections 2.3, 2.4 and 2.5.

Professionals, such as engineers and teachers, were thus expected to fulfil professional responsibilities and keep their professional work practices up to date. For example, engineers were expected to: "possess fundamental knowledge and skills; develop the capacity to engage in complex forms of professional practice; make judgments under conditions of uncertainty; learn from experience; create and participate in a responsible and effective professional community" (Sheppard et al., 2006, p. 429). Yet, becoming a professional or staying a professional in times of the changing nature of work was believed to impact the demands for individual workers regarding professional learning and practice. For an elaborated exploration see Section 2.6.

The possible changing demands for workers' skills in this digital technology-impacted context was believed to have its consequences for workers' professional development. It was believed to change how workers developed the knowledge to be or become professionals. This thesis does not focus on the nature and conceptualisation of knowledge and my basic discussion does not unravel all the complexities regarding knowledge. However, knowledge was understood as follows: Whereas the common knowledge view provided an understanding of knowledge as something that can be acquired and developed as an individual feature, a more contemporary view of knowledge, namely, that of a practice perspective (Hager et al., 2012) was identified. A view that saw knowledge as something that was participated in and was connected to a practice. The different views of knowledge identified for professional learning were often discussed in connection with the acquisition and participation paradigm discussion. Even though research on the changing nature of work was conducted, there has not been much done to investigate professional practice and learning for work in this specific digital technology context. This point was supported by other researchers in the field of learning for work. For example, Fenwick and Edwards stated, "There has been little detailed examination of the implications of digital technologies for professional practice" (Fenwick & Edwards, 2016, p. 118).

So far in this thesis, the study background was provided by focusing on the changing nature of work. More specifically, about the digital technology driver and its possible effects on learning for

work of individual workers. Next, the focus shifts to the problem purpose statement that addresses the study problem concerned and how it was conceptualised in the research for this thesis.

1.3 Problem purpose statement

The world of work was believed changing with the use of digital technologies in work that had the potential to influence organisations but were also believed to impact the professional human demands of the workplace (Colvin, 2015; Ford, 2015; International Labour Office, 2017; Schwab, 2016; Susskind & Susskind, 2017). Because of the in section 1.2 discussed digitalisation of work, the digital technology driver was believed to impact the work of individual workers. An impact in the sense that it could change how they practised their work, the required individual and collective skills, and thus impact professional practices (Fenwick & Edwards, 2016, p. 117). Also, learning for professional practice. Although engineering professionals were expected to match their professional responsibilities with professional practice in the context of the changing digital nature of work, they, however could experience difficulty in becoming or staying a professional. These problems could potentially be attributed to three mechanisms of digital technology that affected individual engineering professionals. The first was that digital technology could change work by either replacing or complementing work activities attributed to digital workplace technologies. The second were skill changes by demanding skills to work directly with digital technologies. Lastly, the third applied to a change of existing skills, beyond those required to work directly with digital technology. These mechanisms attributed to digital technology were believed to result in implications for professional responsibility and learning.

Some indicated that “There has been little detailed examination of the implications of digital technologies for professional practice” (Fenwick & Edwards, 2016, p. 118). Although research was conducted on the changing nature of work. However, little was known about the actual work practice of these engineering professionals. Therefore, the need was identified to focus on the work practice to provide a contribution to improve the understanding about the implications for professional practice attributed to working with digital technologies. It appeared in workplace learning research that work conceptualised as a practice could be connected to learning and change. Subsequently, the learning theories that fitted contemporary descriptions of human and digital technology relations were found located in the sociomaterial theories, namely, Practice-Theory and the Actor-Network Theory. Based on the learning theories that often discussed the paradigms of learning as an acquisition and a participation, a need was identified to focus on the place or mechanism for learning in this changing digital professional context. Therefore, the purpose of this research was to explore

what happened with professional responsibilities in the context of digital technology in work. Explicitly, for the case of the selected engineering professionals working in the construction industry. Furthermore, this was selected for the ability to include a focus on possible required skillsets to be a member of the selected engineering practices of *preparing project reports* and *developing construction plans* in changing digital environments and how this could relate to different ways of learning for work. This was done by conducting an explorative sequential mixed-methods case study among a selection of engineering professionals coming from three countries across the globe. The countries were selected based on the status of innovation in the country which will be elaborated on later in this chapter. A need was identified to further explore the implications of digital work technology on professional practice to develop detailed information. The focus on professional practice and possible relations to digital technology were identified as the first required focus of this thesis. Secondly, the focus on learning for professional practice was identified as a key to understand, from an educational point of view, where engineering professionals might learn best for professional practice in a changing digital technology work context. Therefore, the main question this thesis addresses is:

What is the role of digital technology for the work practice of engineering professionals' working in the construction industry - how does it relate to their professional responsibility and learning?

This general main question led to two more specific research questions which are shown in Chapter 5. The question led to the identification of a need for a mixed-methodology study. A stronger focus on the final qualitative part to explore professional perspectives on how to learn for work in a changing digital technology work context and the relations to their professional responsibilities were identified. This design was required to develop an understanding of three major research areas of concern, in the light of the digital technology attributed to be the work change driver. First, it required an understanding of what constituted the core engineering work practice of *preparing project reports* and *developing construction plans* for engineering professionals' working in the construction industry. Second, it required an understanding of the work skills required to be a member of that selected engineering practice. Lastly, it required an understanding of how, and where professionals learn to be, or become a member of the for this thesis selected engineering practice. To conclude, these three needs for the development of an understanding of a digitally changed professional work practice required in turn data from different sources. Data with the use of surveys and interviews as the primary data form with documents and literature to position and support the data.

This explorative investigation into the human-digital relations contributes to the body of knowledge in four ways. First, it provides a detailed and focused account of the implications for professional responsibilities and learning for one particular group of professionals in one particular industry. Which has led to the understanding that the human-digital interactions in *professional planning and reporting engineering work practice* can now be understood as unique shared professional engineering responsibilities which rely on the *performing* of heterogenous human and nonhuman *actors* who rebuild the engineering work practice. This first understanding has led to the second understanding. The learning practice for professional planning and reporting engineering practice in relation to human-digital interactions can be seen as a unique sociomaterial networked relative stability in which learning opportunities arise based on the significant *performing* of new digital *actors*.

Second, the exploration in this thesis also contributes to conceptual knowledge by providing an account of the notion of professional learning for becoming or staying a member of an engineering practice. Being understood as something that occurs in a sociomaterial networked practice that changes – a *relative stability* - and for which learning should include a work practice-based account in education. This is important since education and professional learning programs should consider including a practice-based account in their program.

Third, the exploration in this thesis also contributes to knowledge by adding to methodological considerations for researching learning for work since a novel focus on two units of learning is used. The focus is on learning residing in the individual and learning residing in the work practice. Fourth and finally, this thesis makes a modest contribution to understandings of sociomaterial sensibilities by providing an empirical account of the ways how materials - digital technology- are taking part in a specific social-interaction -professional engineering work- which remained under examined till date.

These contributions may be used to inform (1) the further investigation of the work-practice and learning of engineering professionals and (2)the implications of a changing understanding of professional learning could potentially promote better-informed decision making about the professional development of individuals in the professional practice and in the preparation in education. The details of the specific case central in this study are described next.

1.4 Setting the case of engineering professionals in the construction industry

The extent of the impact of the digital technologies may be affected by the localised development of a country and by specific industries but due to the current status of globalisation, its impact was identified as a global concern. However, this impact was believed to differ across industries and professions. Therefore a selection for this thesis was made on the engineering professional working in the construction industry. The construction industry is an important sector on which to focus an investigation about engineering professionals' learning for work in the digital technology context for its unique nature, and its essential role in the functioning and growth of a country's economy. The construction industry is crucial to a range of areas involved in the development of the economy, such as in infrastructure, housing, and transportation. Furthermore, they are also building the physical spaces where knowledge creation takes place (Bower, 2010). Denise Bower, professor of Engineering Project Management at the University of Leeds revealed how the construction industry contributes to the economic development of countries as follows: "It is a large and diverse sector which includes a wide range of different kinds of work, high specialist work, and high labour intensiveness" (Bower, 2010, p.2). These various work specifics make the projects in the construction industry not only important for economic development in all countries but also make it an industry with multiple challenges for the professionals working in the industry.

Engineering professionals defined for this thesis were those professionals that performed mid- to high-level engineering work in the construction industry. Engineering professionals were historically understood as those professionals who were responsible for the building and development of our social structures or the so-called builders as can be seen below:

> In ancient Egypt the master builder, who was also an architect, engineer, and builder, usually held a very high status and was responsible for managing the whole process of quarrying the stone material, transporting it to the construction site, overseeing the whole construction, and organising the immense labour force (Chiu, 2011, p. 59). (as cited in Figueiredo, 2014, p. 9)

The quote above shows that engineering professionals were thus historically understood as professionals with a wide range of responsibilities and a high status in society. This is still the case for engineering professionals today. The engineering professionals defined for this thesis were those that aligned with the guidelines set by the professional bodies in the various countries and had several different job titles, each with possible varying skill sets. If using the educational attainment classification, however, the professionals were technicians, surveyors and engineers who had mid- to

high-level skillsets (Lerman, 2017) and their managers. But how were these mid- and high-level skillsets defined? By using the educational attainment classification, different definitions of, for example, mid-level skilled work, existed. Firstly, some defined the skillset in terms of jobs that required some training after high-school but not a four-year college degree (Modestino, 2015), while others found that it required training and a university degree (Lerman, 2017; Modestino, 2015; Wheelahan et al., 2015). Indeed, the education pathways leading to a mid-level occupation in the construction industry, for example, technicians, mostly involved diplomas or professional skill development programs, whereas engineers often required a Bachelor of Engineering (Sciences) degree. However, the focus of this thesis is on the engineering professional and learning for work and no demarcation relating to their educational attainment was made. Therefore, the focus seen from an educational attainment point of view is on higher levels of vocational education, college and university levels. However, it was researched from the point of view of professional learning. This had conceptual consequences since the focus on professional learning meant in this thesis, must not be confused with the professional learning seen from a performance management point of view. It should rather be seen as the professional learning that is part of the preparation for work to become a professional as well as staying a professional which may or may not take place in education.

An investigation about learning to be an engineering professional or staying a professional required firstly an understanding of what a professional is. From a historical point of view, the different authors agreed, according to Abbott, that:

> a profession was an occupational group with some special skill. Usually this was an abstract skills, one that required extensive training. It was not applied in a purely routine fashion, but required revised application case by case. In addition, professions were more or less exclusive. (Abbott, 1988, p. 7)

The quote above shows that professions were thus occupational groups with special skills, and those working in those professions were the professionals. Engineering, like law and teaching, was one of the professions and has its own associated regulations and identities which become visible when looking at the professional bodies that regulate the occupation or profession. It often takes a specific trajectory, formal study, some form of accreditation and sometimes a certain amount of practice time to be acknowledged as an engineering professional (Kaspura, 2019). For a brief discussion of the development of professions, and the resulting knowledge required to be a member of that professional practice, I continue to draw on the work of Andrew Abbott. His view of knowledge control and skills were identified as relevant. This professional control was relevant because control

could imply that adaptation to change, such as changes due to shifts in digital technology, in work could slow down. In this context, it was the control of knowledge and skills that became visible and could impact the evolution of the profession:

> My underlying questions concern the evolution and interrelations of professions, and, more generally, the ways occupational groups control knowledge and skill. I have already argued that the evolution of professions in fact results from their interrelations. These interrelations are in turn determined by the way these groups control their knowledge and skill. (Abbott, 1988, p. 8)

The citation above shows the knowledge and skill control of professional groups and indeed, Abbott also referred to craft occupations being in greater control since their ability to regulate the techniques they employ. He argued that this becomes relevant when they are regulating old techniques, and thus, I believed, made the professionals more likely resistant to change based on two ways of controlling:

> To control such an occupation, a group directly controls its technique. The other form of control involves abstract knowledge. Here, practical skills grow out of an abstract system of knowledge, and control of the occupation lies in control of the abstractions that generate the practical techniques. (Abbott, 1988, p. 8)

The quote above shows that control can be executed by changing the process -techniques- and by changing the abstract knowledge preceding the skills. Both are powerful ways to control the work practice of a professional. Although a discussion about the historical development of the professions had been interesting here, it was beyond the scope of this thesis, given its focus on the control and power of professions.

To conclude this section, professionals for this thesis were thus understood to be the so-called builders of our social structures and were defined as engineering professionals'. Educational levels of these engineering professionals were not the guiding principles but could range from vocational up to university levels. The engineering professionals' status is relevant to understand since it can slow down adaptation to change due to control of knowledge and skill in the particular professions. This means that the adaptation to change, such as the change associated with digital technology and the actual change of skills and knowledge, can be slow. The regulated skills and knowledge among professional bodies do not have to imply a reflection of the current reality of engineering practice. Therefore, I believed that any empirical investigation into the perspectives of professional bodies to understand the learning for work in a changing context became less interesting

than the views of the professionals themselves. For this, an understanding of engineering practice was required, which is discussed in Chapter 3.This section has discussed that being a professional might delay the change of knowledge and skills because the traditional regulating power of being a professional might define the skills while change occurs.

1.5 Researching learning for work and digital work technologies

Researching learning for work involved an interesting multidisciplinary but challenging field in which different role players were involved. For example, role players such as politicians, educators, economists, industry professionals and researchers were part of the field, but all had their own agenda, use of language and approach that proved difficult to merge. The different aspects of both a variety of different role-players as well as the multidisciplinary nature made researching in this field a difficult task. Moving forward by addressing the different components that took up the research on engineering for work learning, the following two subfields, work and learning, are relevant to elaborate on and help putting this challenge into perspective.

First, researching learning for work included the field of work. *Work* in this body of research was conceptualised in different ways among the different role players, but most researchers seemed to agree that it came down to the work that is performed in a professional sense. Disagreements were, for example, found in discussions about the understanding of work "comprising clearly definable sets of skills and knowledge" (Dirkx, 2011, p. 299) or understanding work as a practice (Hager et al., 2012). For example, work can be perceived as an individual worker's activity, or it may be perceived as something executed by a group of people, as an activity, or, as a practice on its own. "Practices should be seen as recurrent processes governed by specifiable schemata of preferences and prescriptions" (Cetina, 2001, p.175) or as practice seen from a post-humanist approach that considered "science as activity" and re-evaluation of human and nonhuman entities (Schatzki, 2001, p. 11). The major understandings in workplace learning research appeared to centre around the activity in work. Secondly, it also included the field of learning for that work involving further conceptualizations and role-players. Among researchers on workplace learning, learning was, for example, conceptualised as a social event (Lave, 1991), as an action which is based on activity (Engeström, 2010) or as sociomaterial (Fenwick et al., 2012; Hager et al., 2012). Also, a distinction between professional learning and educational learning had to be considered first since both appeared to have different conceptualizations and purposes.

In this thesis, the focus is on the learning associated with becoming, or developing further as a professional. Which is understood as professional learning since it was difficult to make a distinction when professionals were referring to their learning. Learning for practice was among some, such as Billett , understood as a collective and "their pedagogic qualities are shaped by participatory practices. That is, how individuals engage in the inter-psychological process of thinking – acting – learning through workplace activities" (2002, p.61). Boud and Hager, (2012, p. 20) included the idea that this professional development often had no "development" in the biological sense of the word and suggested that it had to do with the use of the two metaphors/paradigms 'acquisition' and 'transfer' that constituted the common-sense understanding of learning. As such, the developmental process of learning received less attention in making professional learning more measurable and visible. Adding a specific context to the field of learning for work, in this case, that of digital technology did not make the task easier since digital technology had complicated associations of its own. In fact, it resulted in including another focus and additional conceptualizations in addition to the research field of learning for work. Digital technologies are often referred to in this thesis or were referred to by others as 'Information and Communication Technologies' (ICT), 'Information Technology' (IT) (Susskind & Susskind, 2017) or even sometimes referred to as 'computer technology'. The different terms and their use were not meant to distinguish among specific branches of understanding but often appeared to be changed interchangeably for the same meaning. A meaning of the 'processes and tools based on Information and Communication Technology' which I defined at the start of this chapter.

1.6 The nature of work is global but is influenced by its context

I believed that I could not rely on solely looking at specific country contexts without expanding the view to a global context. The need for a global context was identified because our world is expanding fast, and issues such as offshoring in business, international education, cross-border business operations and the price advantages of remote work resulted in the need for a global perspective in researching learning for work. Other researchers supported this global view. For example, Bridget O'Connor, a workplace learning researcher from the USA, argued, "Workplace learning, and its research, was global because that is the nature of work, and thus, it was difficult to separate workplace learning in the USA from trends in other countries" (Malloch et al., 2011, p. 202). Sako (2017), suggested that there is the case of the international migration of professionals, which is one example of the globalisation of work which is relevant for the global focus of workplace learning research, and also indicated that professional migration is relevant for engineering. This further

supported the need for a global view. On the other hand, Malloch et al. (2011, p. 202) and other workplace researchers argued, "Learning processes and approaches are greatly influenced by differences in workplace settings (health, education, business, non-profit etc.) and context" and this, in turn, indicated the need to look at context specifics. Therefore, to cater to a specific context, a country approach in the global investigation was considered relevant, considering the need for a globalised discussion in researching learning and work. Also, since the associated substantial differences resulting from differences in context, I cater to a global perspective by including an exploration of literature from across the world in this thesis. However, the dominant field remains workplace learning.

The developmental state of countries across the globe varied significantly if sources such as the global competitiveness index had to be believed. The index measured indicators from different countries and compared their ranking amongst one another (Schwab, 2018). The rankings of the three selected countries for this thesis are shown in Table 1.

Table 1.

Technology indicators in the selected countries

No.	Technology Indicators	South Africa	The UAE	Australia
1	Technological Readiness	54	24	27
2	Innovation	39	25	27
3	Availability of latest technologies	45	13	27
4	Capacity for innovation	30	15	24
5	Company spending R&D	32	22	25
6	University – Industry collaboration in R&D	29	25	33
7	Government procurement of advanced technology products	57	01	71
8	Availability of scientists and engineers	100	03	16
9	Firm level Technology Absorption	38	10	24
10	FDI and Technology Transfer	60	04	27

*Note. The numbers in this table are the ranking of the indicator in the respective country. The data is adapted from the global competitiveness report rankings (*Schwab, 2018)

The report showed that US states, Australia and Europe were in a further developmental state and countries such as South Africa and the United Arab Emirates were in a moderately developed state. Although, when looking at the indicators for innovation and technology - technological readiness, availability of latest technologies, firm level technology absorption, FDI and

technology transfer- in Table 1, the UAE is relative to other countries well developed in these areas since the indicators are in the top of the global ranking . It was therefore decided for the research to include data from different countries. South Africa, Australia and the United Arab Emirates were identified and selected for this purpose as described in Section 1.3. It must be made clear that not all countries were developing at the same pace, nor were they at the same level of social, human and technological innovation. For instance, as shown in Table 1, the UAE was in the top 20 regarding having the latest technologies at their disposal, compared to South Africa ranking at 45. While this lower ranking on technology availability may had seem to indicate that South Africa was left behind regarding some innovations, the country was actually not that far behind regarding the average innovation score. Their positive innovation score indicated a positive outlook for the future. Another issue of concern in the case of South Africa was the country's position in numbers of available scientists and engineers -ranking 100, where the United Arab Emirates ranks 3 and Australia ranks 16- as technology is developed by scientists and engineers. The fact that the era of 'the Internet Of Things' had begun, see Section 2.6, and that new technologies formed the way business was done, indicated a serious disadvantage to South Africa in terms of productivity and competing in the global business world.

1.7 Changing digital work environments and connections to skill discussions

Digital technologies in work were among other things like globalization, the knowledge society, increased uncertainty, high-performance workplaces, and the change of economic structures, (Humburg & Velden, 2017, p. 201) associated with changes in industries. However, the researchers argued that no agreement among researchers about the change drivers existed, neither about their names nor the definitions that were used. They argued that the change drivers were all connected and that Information and Communication Technologies (ICT) was the main driver of them. They referred to the concept of technological change. Research on changes in the labour market and, more specifically, changes in the supply of digital technologies used in work, has received continuous attention from researchers since the first industrial revolution. The focus among economist researchers was often on the demand for skilled and educated labour and the wage return. For example, the American economist Pritchett (2000) had the following explanation for the demand for educated labour, "One is that education conveys skills that make labor more productive. In this case the demand for educated labor will rise when the skill intensity of the economy rises." (p. 24) and complemented this with the notion that improved ability to adapt was connected to education of which both would increase the demand for educated labour in times of change.

EXPLORING LEARNING FOR WORK IN THE CONTEXT OF DIGITAL WORK TECHNOLOGIES

Two streams of debate in research about the technology driver that were relevant for individual workers' skills were identified. The first was about an understanding of a causal relationship between technology and skills which looked at a narrow understanding of the notions of skills-mismatch. The second debate looked at replacing and complementing human work from a broader understanding than just the notion of a skills-mismatch and beyond proving causality between technology and skill changes. The latter is thus focusing on the broader notion of the implications of the digital technology driver and its relation to professional work.

The first debate was found in the deskilling and post-industrial theories. Handel (2017) argued that methodological issues such as problems in generalizability and reliance on case studies hindered its progress. The aim in the research stream was to measure a direct disconnection between the skills workers possess and the skills required for the job. It was based on the aspect that technological advancements required more skills from workers and skill upgrading was required (Attewell, 1987). However, although an understanding of possible relations between technology and skills was identified as relevant for the current thesis, the aim of this thesis was not to embark on a deskilling investigation. Since, the objective was not to prove a disconnection or connection between the demands of work and professional skills. The causal connection between computers and skills was not proven but the higher wage indicators suggested that more skills and training were required to work with computers (Handel, 2017, p. 94). Furthermore, a demand for more cognitive skills was associated with computers "because they increase the information content of work and decentralize problem-solving (Autor et al., 2002; Spitz-Oener, 2006)" (Handel, 2017, p. 94). Handel, continued to suggest that there was no real conceptual framework, and the reliance on aggregated measures such as educational attainment and computer investment were the main data reliance in this branch of research. According to Kaplan (*Jerry Kaplan: 'Humans Need Not Apply' | Talks at Google*, 2015), the question was not whether the technology would be disruptive, but to what extent the impact would be disruptive. Kaplan referred to the automation of tasks as an extension of the industrial revolution and saw the impact as being negative for society with rising inequality. "Kaplan's ideas around the obsolescence of human intellectual labour (Kaplan 2015)—have not suppressed our appetite for progress" (Lewin & Lundie, 2016, p. 236) and the discussion centred around if "human intellectual labour" would become obsolete. However, that focus is not further discussed in this thesis.

The second and more relevant debate for this thesis was the question of which work tasks could be executed by digital technology that were previously done by human professionals (Susskind & Susskind, 2017) or also referred to as computer capabilities (Elliott, 2017). This raised questions

about human work, as to which professional work tasks were already being executed by digital technologies or were likely to be taken over by computers in the near future. The discussion centred around the replacement of human work tasks or the complimenting of human work tasks. Underlying these discussions were concepts such as, the diffusion of technology that defined how quickly these technologies were spreading in industries and in organizations; skills requirements among management and workers to adapt to working with these new technologies and professional skills that were useful in complimentary technology use. Therefore, following the discussion above, this thesis adopted a broad view of a possible skills mismatch discussion. A view in the sense that it focused on the second debate about whether digital technologies will be task-complementary or replacing at the professional work level. This removed the focus from an individual skills mismatch discussion. However, despite adopting this broader understanding of digital technologies, tasks and skills. The discussion of the relations between skills and digital technology investigated in the 'skills mismatch' body of work identified being relevant to the understanding of possible relations between professional work and digital technologies.

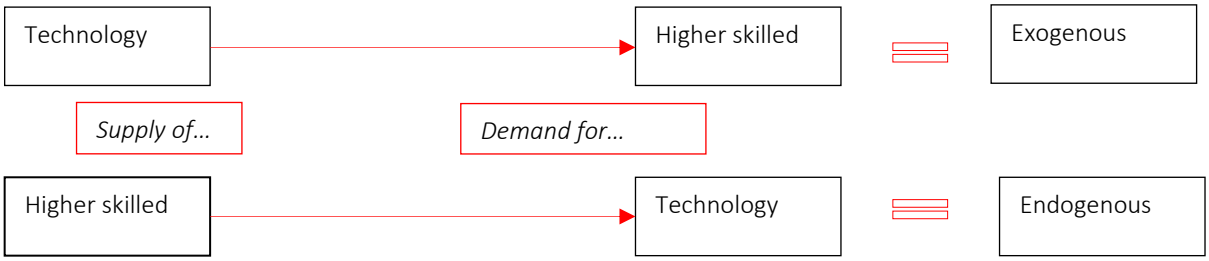
One approach and connected theory was that of the skill-biased technological change theory (SBTC). Although the SBTC-theory was contested based on the directions of the causality, I believed that the SBTC-theory was useful as it indicated the possible connections between technology, skills and education:

> Mainstream labour economists focused on the spread of computers, arguing new technology raised the relative demand for skill and increased returns to education and other human capital (Katz & Murphy, 1992; Autor et al., 1998). This theory of skill-biased technological change is dominant amongst labour economists and favoured by some sociologists (e.g. Fernandez, 2001), education researchers, policy analysts, and popular writers. (as cited in Handel, 2017, pp. 93–94)

Following Humburg and Velden (2017) the two hypotheses of the direction were found in the exogenous and endogenous hypothesis of the skill-biased technological change theory depicted in Figure 1. The exogenous hypothesis, on the one hand, appeared to favour higher-skilled workers because routine work could be replaced by technology, which was associated with lower-skilled workers. Higher-skilled workers were expected to be more capable of dealing with new technologies. The endogenous hypothesis, on the other hand, argued that the large supply of highly skilled workers had activated the demand for technology.

Figure 1.

The direction of SBTC-theory - exogenous and endogenous



Note. The flow in this figure shows the differences between the forms of the SBTC-theory
The data is based on an economic centered literature review.
Source: de Munnik, M. (2020). Exploring learning for work in the context of digital work technologies: the sociomaterial case of engineering professionals in the construction industry [UNPUBLISHED Doctor of Philosophy thesis]. University of the Witwatersrand.

The supply of high-skilled labour, as shown in Figure 1, activated the technology demand. The Endogenous Technology hypothesis related education to technological change because "the stock of human capital determined the rate of growth" (Romer, 1990, p. 71). For example, the famous Pin Factory story of Adam Smith where workers became more productive with the division of specialised work tasks instead of executing all tasks, was endogenous. Then, the Directed Technical Change hypothesis indicates that technological progress is endogenous and that the "nature of technology" adapts to the circumstances (Acemoglu et al., 2003, p. 26). Subsequently, this process feeds into the demand for educated workers and thus triggered implications for the relationship between the demand and supply of skills (Acemoglu et al., 2003). See for an elaborated economic discussion 'APPENDIX A – AN ECONOMIC PERSPECTIVE'. Trends around changing work practices and "changes in job tasks resulting from technological change could lead to either an improvement or deterioration in the match between actual and required skills" (Allen & de Grip, 2012, p. 3238). For example, according to the World Economic Forum, 39% of employees' core skills would change between 2015-2020 in South Africa. In the Gulf Region, the figure was 21%. However, South Africa's capacity to respond to these future skill needs, in particular, was low (Leopold, 2017, pp. 7–8) but all three countries had their own individual challenges which is explored next.

1.8 Problems with finding skilled workers

The countries that were selected in the thesis were all having individual problems with finding skilled workers. This was visible in South Africa, particularly for filling positions in the engineering field and in the construction industry, because of their being on the critical skill lists and the governmental efforts to attract foreign workers in these areas (Department of Higher Education and Training, 2014, 2018).

Then, the United Arab Emirates, like South Africa, was also experiencing problems with finding skilled workers among its nationals. The construction sector in that country contributed significantly to the economy. Finally, Australia also depended, like the UAE, on attracting foreign workers to fill the positions in the construction industry. For example, the 2019 report from Engineers Australia about the engineering profession shows that about 58% of the engineering professionals in the country were foreign workers. The three countries had one particular thing in common and that is that their education system evolved from the predecessor of the Anglo-Saxon education system. All three countries were influenced by the British and this impact can still be seen in their current education systems. Therefore, what follows is a closer, but brief look into the developmental state of the three selected countries alongside a brief overview of their schooling and post-schooling education system.

South Africa has serious developmental issues. South Africa is a country on the southern tip of Africa with a population of about 55,9 million, an economy of 294 billion US$ (Schwab, 2018) and high unemployment levels. In 2015, unemployment was 25,4 % (OECD, 2017) but increased to 27,6 % in 2019 (Statistics South Africa, 2019, p. 6). This presents serious development challenges for the country. In fact, the unemployment among the working-age population (15-64 years) is even higher, as indicated in the quarterly labour force survey of Statistics South Africa, with a total of 34,9% in 2015 (STATS, 2015). This indicated that the population was experiencing socio-economic challenges. Due to developmental issues such as social inequality alongside highly concerning issues on the index of human development (Schwab, 2016), the country was regarded as an emerging country in a medium-developed state. Not only was the country emerging, but it had also faced, what is widely considered to be the most severe form of racism in the world during the apartheid regime that ended in 1994. The apartheid regime has had a lasting impact on the economic and social position of the Black African population in particular. The country's construction sector made up 4% (Roux, 2017) of its economy. About 8,9% of the working population was employed in this sector in 2015, and 8,2% in 2019. About 16% of the unemployed originated from this sector in 2015, and about 18% in 2019 (Statistics South Africa, 2019; Statistics South Africa, 2015). These statistics suggest that the sector is likely to continue experiencing problems by just looking at the development between 2015 and 2019. Post-school education in South Africa included the formal Technical Vocational Education and Training (TVET) colleges, skill development programs of the Sector Education and Training Authorities (SETA) and non-formal post-school training (Department of Higher Education and Training DHET, 2013). Technical and vocational education in South Africa was subject to major historical developments since the establishment of a democratic post-apartheid state. The post-apartheid era has perpetuated and created new and significant disadvantages for the black population in the country. Therefore, the

system was greatly influenced by the history of the apartheid government (Arfo, 2015; Kraak & Young, 2000; McGrath, 2011). The establishment of technical colleges in the country dated from the Apprenticeship Act of 1922. However, the act specified that these apprenticeships were only accessible to the white working-class; black working-class apprenticeships only became available in the 1980s (Arfo, 2015; Wedekind, 2016). The Further Education and Training Act of 1998, and the Skills Development Act of 1998 (SDA) were the first pieces of legislation of TVET education in South Africa. Apparently, a central aim of the SDA was to ensure that employment development opportunities would be inclusive as regards historically politically and economically disadvantaged groups, as is to date relevant in such policies.

Recent developments in TVET education have indicated serious concerns with this system. These included low pass and through-put rates, lack of quality programs, and the generally low quality of graduates (Arfo, 2015). As a result of these issues, the system had again attracted the attention of policymakers. It was expected that, due to the high population levels in Sub-Saharan Africa and the South Asian countries, in particular, amongst the young population, these countries would contribute to +/- 60% of the global labour force by 2030 and expected filling the gaps existing in the developed countries (Asian Development Bank, 2014; Mourshed et al., 2012; Rajadel, 2017). At the same time, the developing countries could experience a lack of medium- and high-skilled workers and too many low-skilled workers. This shortage of a higher skilled workforce has thus potential implications for filling the demand for mid- and high-level skilled workers across the globe but also in their own country. Therefore, TVET, college and university models of vocational education are highly relevant to address this supply and need. Thus, as indicated by Roux (2017), the critical issue to consider in the case of South Africa was whether the South African labour force had the skills and training to meet this need. The likelihood of this was debatable since it was beyond being reflected in the list with occupations in demand of the South African Government (Department of Higher Education and Training, 2014, 2018) also visible in the different views on this situation expressed by stakeholders in the industry (Global Apprenticeship Network GAN, 2017).

The United Arab Emirates has rapidly developed its education system. The United Arab Emirates is a group of seven emirate states near the Arabian Gulf, also called the Gulf States. The Emirates have a population of 9,9 million, an economy of 371 billion US$ (Schwab, 2018), and a low registered unemployment rate. The construction sector contributes 4,4 % (Ministry of Economy, 2016) of its economy. Especially in its main Emirate State, Dubai, construction was regarded as an important part of the economy. This was since the industry included a significant percentage of the

total labour force, with 33,47% in 2014, and thus was of essential value for the country's economy. Nevertheless, regarding the importance of the sector for the economy, the country, like South Africa, had its own particular challenges finding the skilled workers it required and was to a large extent dependent on attracting offshore workers to fill the skill gaps in the various industries. The research of Alhebsi et al. (2015) provided initial insights into the historical development of the UAE's education system. The research showed how the country's education system officially emerged after the constitution of the first six Emirates in 1971, and how previous education had often been based on religious foundations. In addition to religious education, a form of informal apprenticeship training was a common way to transfer skill-based knowledge and learning, and often took place through the transfer of knowledge and skills within families. However, post-school education and training in the United Arab Emirates have gone through some significant changes. For example, the country established a centre for technical and vocational education in 2010 (United Nations Educational, Scientific and Cultural Organization UNESCO and International Centre for Technical and Vocational Education and Training, 2015). The governmental strategy 2010-2020 envisaged a student-centred approach with the purpose of developing students' skills, knowledge, and readiness for higher education. The focus on skills development in the region was also specified in the OECD's report, 'Better skills, better jobs, better lives' (Organisation for Economic Co-operation and Development, 2015). The following objectives in the governmental strategy for 2010-2020 supported this focus and indicated the need for a focus on future workplace requirements:

> Ensure high-quality curriculum is in place so that students are best prepared for the knowledge economy; contribute to curriculum development by providing input around the knowledge and skills needed to work successfully in the workplace of the future. (Ministry of Education, n.d., p. 2)

Then, the Higher Colleges of Technology[3] have since 1988 been responsible for the delivery of technical and vocational education to meet the needs of industries, and Universities for the four-year Bachelors. Further, the Human Development and Knowledge Authority [KHDA] is one of the authorities in the country responsible for the development of knowledge and human resources (Personal communication with Dr.Kenaid, 2017; UNESCO & International Centre for Technical and Vocational Education and Training, 2015; Knowledge and Human Development Authority, n.d.b, n.d.a) and its purpose was to ensure the quality of education. The examples of developments above indicate

[3] http://www.hct.ac.ae/en/

that the country has gone through some major developments regarding post-school education in a short time and new developments were constantly and rapidly emerging with a strong governmental input which appeared based on the multiple initiatives and events around the future of education and knowledge, such as the knowledge summit in 2019 (Mohammed bin Rashid Al Maktoum Knowledge Foundation, 2019), and the accompanying report. In this report, the connection to education in a changing digital context is made and the demand for improved skill development (*The Future of Knowledge: A Foresight Report 2019*, 2019, p. 2) which seemed to reflect the awareness of the government about the topic central to this thesis.

Australia has a strong education system but relies on foreign workers. Australia is a country in Oceania with a population of about 24,3 million and a 1259 billion US$ economy alongside a low unemployment rate (Schwab, 2018). Despite the strength of its economy, most of Australia's rankings were not among the top 25 in the world, if looking at the global competitiveness report 2018. "Australia performs comparatively better in the higher education and training pillar (9th), which reflects its capacity to produce a large pool of qualified workers." (Schwab, 2018, p. 50).

The construction sector contributed to the country's economy with 8%. The construction industry employed about 4.1% and the engineering services industry 16.8% of the total of 329.957 employed engineering professionals in the country (Kaspura, 2019). A significant detail is that they relied mostly on attracting skilled workers from elsewhere for their engineering workforce to fill the skilled positions. About 58% (Kaspura, 2019) of Australia's engineering professionals were foreign engineers. This is remarkable since their higher education and training pillar was among the top 9 in the world in the global competitiveness report and they were associated in the same report with being able to develop qualified workers (Schwab, 2018). Australia has a strong higher education and training system and a good quality education system in general (Schwab, 2018). However, the country relies on extracting foreign talent to fill their work positions and this is expected to continue due to the worldwide skill shortages in countries (Phillips, 2006). Vocational education and training have gone through reforms in 2014 and the system was led from the governmental side, namely, by the Council of Australian Governments [COAG] Industry and Skills Council. The funding of these skill activities happens triparty.

> VET delivery in Australia is largely funded by the Australian, state and territory governments. However, companies and individuals also contribute to the cost of training. Companies contribute by purchasing training for their employees, while students contribute through the payment of course and administrative fees. ([i] https://www.education.gov.au/about-skills-sector)

The chapter showed that the three countries have distinct educational systems, but all three have, to some extent, separate departments for skills development in their country. In a historical sense, the countries shared some common features in terms of colonisation and the relatively late development of their Western educational system but with distinct consequences. The current section was by no means extensive enough to provide a final and complete picture of the educational systems and professional development in the countries but the investigation into the social institute of education is not part of the focus of this thesis. Therefore, so far, the discussion has shown a different context in the selected countries that differs on innovation and technological development. It also showed a similarity among them, namely that they have all been influenced by the British educational system. In the following section, I discuss the outline of the rest of the thesis.

1.9 Outline of this thesis

This first and introductory chapter of this thesis discussed the idea that the changing nature of work might impact the requirements for professional work and therefore, the associated learning for work. The chapter further showed that we do not know exactly what engineering professionals do in practice in times of a changing digital technology context and how they learn for this digital impacted practice. Chapter 2 continues the exploration by looking into the digital technologies in relation to skills and the construction industry. Chapter 3 continues the exploration by what is already known in Workplace Learning Research on engineering skills and learning and the common methods to adopt in research. The same Chapter shows my belief that researching learning for work could benefit from adopting a view of learning as both residing in the individual and in the practice. Chapter 4 proceeds with drawing on sociomaterial theories (Practice-Theory and *Actor* Network Theory) and builds the conceptual framework that this thesis follows. Chapter 5 elaborates on this conceptual framework by showing the selection of a mixed methods sequential case study by using a self-developed survey and interview. Chapter 6 describes the results from the Quantitative part of the study, the survey phase and shows that the variances among engineering professionals are at stake. Chapter 7 continues with providing thick sociomaterial sensible stories based on the interviews with the engineering professionals. Which are organised around the 5 principles of practice framework as identified in Chapter 4 as being useful to connect learning, change and practice. Chapter 8 extrapolates major insights from the two results chapters by answering the research questions and explaining them with the literature from previous chapters. Finally, Chapter 9 provides a synthesised description of each of the Chapters in the light of the central research question, moves to the contributions and makes modest suggestions for future work as well as concluding with the limitations of this thesis.

Chapter 2, addresses first the contextual background specific to the case of the construction engineering associate professional by attending to the discussion about the digital technology impact on individual workers and on the specific digital technologies commonly found in the construction industry.

CHAPTER 2 -DIGITAL TECHNOLOGY IMPACTS WORK AND SKILLS

2.1 Introduction

In the previous chapter, the research of this thesis was outlined and it was shown that the changes in the nature of work may impact the skill demands for professionals. At the same time, the exploration in the chapter has shown that we do not exactly know what people do at work, or their relations with digital technology. Therefore, this chapter will discuss the possible impact that digital technologies have on work and on human skills, by using both academic as well as industry literature. The reason for using both of these literature forms is because of an assumed delay, between what has been published in academics and that what is happening in industry (Elliott, 2017). A focus on both which was also based on the different views, since they had each distinct interests and agenda's. In this chapter, it is shown that the main two areas where digital technologies can form relations with working professionals were found in both the replacement and complementing discussion. In the former, the relationship can be perceived as negative because some workers' tasks can be replaced with the capabilities that digital technologies expose. The latter is more likely to be perceived as a positive impact because digital technology can complement professionals in the execution of their work tasks. The digital capabilities that can complement human skills, such as reasoning capabilities, are also associated with higher professional levels because the required skill set is assumed to be more complex. The chapter proceeds with a discussion about the skills needed to work with digital technology and shows that a wide variety of knowledge and skills are associated with working with digital technologies. Skills such as communication skills, people skills and technical skills appear especially relevant. Lastly, the chapter discusses the digital technologies that are specific to the construction industry and highlights the use and understandings about three of them. Two of the digital technologies that are discussed can be understood as recent and modern forms, based on the technology acting as a process, whereas the third example is a digital technology that has already been in use in the construction industry for over ten years.

2.2 The impact of digital technology on professional work

When focusing on the digital technologies that are used in different industries, the technologies seem to change the existing business processes with all their underlying difficulties. However, the further focus of this thesis is on engineering learning and the engineering professional and not on industries. Therefore, I continue following the same direction as Humburg and Velden (2017) and Susskind and Susskind (2017) and focus on the impact of technology on professionals without further embarking on

the economically-centred discussion about the causality of digital technology and skills and the direction of the relation. The focus here is on the concepts that were considered relevant in the light of professionals' work and their learning. This focus may mean that concepts from the economic-centred discussion of causality between digital technology and human skills are only used for improved understandings, without fully embarking on that route of research. Therefore, based on the assumption that digital technologies and human skills are connected in the context of professional work which was discussed in Chapter 1, the focus in this chapter is on the human factor instead of on macro-perspectives. The discussion here further focuses on computer capabilities taking over tasks in human work or complementing tasks in human work. Subsequently, distinctions between ICT as instruments or tools, versus processes are used. The two forms of ICT have their own related consequences for two particular groups of workers, namely lower- and medium-skilled workers versus professional workers. For the lower- and medium-skilled group, "For repetitive, routine tasks—often performed by low- and medium-skilled workers—ICT can be seen as replacing labour. ICT is faster and cheaper than people in *performing* these tasks." (Humburg & Velden, 2017, p. 205). However, these views on routine tasks associated with replacement are not supported by other researchers such as Susskind and Susskind, (2017), whereas for knowledge work and professional expertise among the higher-skilled, ICT can complement the humans in their work but can also make the work more complex (Humburg & Velden, 2017).

Thus, I believed that the relations between digital technologies and professionals can be understood as having the following implications for professionals: (1) replacement of professional tasks in the sense that the digital technology can execute the human tasks. Lower educated workers seem to be more susceptible to replacement because their work tasks are more likely to be taken over by digital technologies; (2) complementing professional tasks in the sense that digital technology can complement and support humans in the execution of their work tasks which may or may not have consequences for the complexity degree of their work; (3) higher educated workers seem to be better able to deal with a disequilibrium when changes occur. An example is a change associated with digital technologies at work, because they possess skills that allow them to process and work with information.

A way to conceptualise the possible relations between digital technologies and professionals is a discussion about innovation and automation. The former has to do with the technology being non-disruptive to the existing work process and enhancing the human work process rather than changing it. In the latter, the technology is disruptive and displaces the traditional way of working,

delivering it in a new way, which may or may not have an enhancing impact (Susskind & Susskind,2017). Automation, from the point of view of technological change, suggests that the likelihood exists that automated skills will be replaced by further automation, and consequently, fewer workers with manual skills would be required than before. On the other hand, higher-end skilled jobs are associated having less work that is susceptible to automation, and with the same scenario, this would indicate that this kind of professional work is less likely to be replaced by automation.

Similar to the innovation and automation discussion of work that has an impact on professionals, the discussion of routine and non-routine also exists in research. Susskind and Susskind (2017) argue that the old understanding of routine/non-routine concepts does not do justice to a realistic understanding of what happens with lower-skilled work when automation happens. However, the routine-nonroutine concepts are used in research to measure which work or work tasks are susceptible of replacement. One could rank jobs based on "the degree to which they require adaptation to change" and the way to do this is by dividing them into routinised and less routinised work (Nelson & Phelps, 1966, p. 69). The prediction is that routinised tasks can be replaced by technology (Elliott, 2017; Nelson & Phelps, 1966) and higher educated workers can 'outweigh' less-educated workers. This approach of a replacement of routinized tasks with computer technologies indicates that computer operated work or computer capabilities substitutes for workers in *performing* "cognitive and manual tasks that can be accomplished by following explicit rules" (Autor et al., 2003).

In line with these arguments is that a possible result of automation could be that employers will require higher-level skills and demand higher entry levels for their future employees (Asian Development Bank [ADB], 2014). Subsequently, a greater need would arise for higher-skilled workers in the workplace of the future. For example, the Council of European Employers of the Metal, Engineering and Technology-based Industries [CEEMET] are arguing that, in the case of Europe, an increased demand for higher-level skills is required with job roles such as managing technicians, technologists and engineers (Council of European Employers of the Metal, Engineering and Technology-based Industries, 2016, p. 8). In addition to the discussion about automation and innovation of work which both imply changes of work, and the associated raised skill demands, I believed that it was essential for understandings of learning for work in the digital era to question both human and digital capabilities.

EXPLORING LEARNING FOR WORK IN THE CONTEXT OF DIGITAL WORK TECHNOLOGIES

Digital technologies are capable of *performing* many human skills which can be understood as *digital capabilities*. In recent years, developments in computer technologies have resulted in digital technologies becoming capable of more tasks. This invites us to revise the widely held view that our machines and systems only do 'routine' work, while humans focus on activities that require dexterity and intelligence. The boundaries are being pushed back as our machines become more capable (Susskind & Susskind, 2017, p. 159). The four identified aspects of computer capabilities found by Susskind and Susskind (2017) are (1) the capability of identifying patterns and making predictions based on historical data, (2) the capability of *performing* human cognitive tasks, (3) the capability of executing and interacting with manual and physical skills, and (4) capabilities of recognizing and *performing* emotions.

The first aspect of computer capabilities, the use of historical data to discern patterns to identify trends and make predictions and generate new knowledge, can also be understood as *big data*:

> Big data analytics, which is a set of techniques and tools used to process and interpret large volumes of data that are generated by the increasing digitisation of content, the greater monitoring of human activities and the spread of the IoT (OECD, 2015a).

Another important feature to mention is that the use of predictive analytics or big data can be used for decision-making processes because it makes data handling and accessing easier and achievable but at the same time can "draw conclusions, offer advice, and provide guidance at the standard of human experts or higher "(Susskind & Susskind, 2017, p. 163) and even innovate professionals' work. Before, one could not work with too large datasets, but this is now possible. Improved and real-time information sharing also opens a world of possible applications in business processes (de Munnik, 2018). Furthermore, "Big data analytics also enables machine learning, a driver of AI" (Organisation for Economic Co-operation and Development, 2017b, p. 24). This is one of the most recent digital technology-enabled processes around.

The second aspect of computer capabilities is the *performing* of human intelligence tasks such as with IBM-Watson. We are now using machines that are capable of cognitive human processes like IBM-Watson and Sofia which "is a computer system, effectively, answering questions on any topic under the sun, and doing so more accurately and quickly than the best human beings at this task."(Susskind & Susskind, 2017, p. 165).

The third aspect of computer capabilities are machines that can interact with manual skills and ability, such as in Robotics. More recent developments have shown that they can operate autonomously which indicates that they do not longer need humans to operate them (Susskind & Susskind, 2017). Developments in the automotive industry have already allowed the use of basic robots to perform the routine tasks that were previously performed by human workers since the 1980s for the manufacturing of vehicles (Susskind & Susskind, 2017).

The fourth and final aspect of computer capabilities identified are systems that can detect emotions such as affective computing. The same robots used in the automotive industry can also be used for sensing and recognizing changes in human behaviour and sense processing that look similar to the human way of sense development (Susskind & Susskind,2017, p. 168).

Although the above is not an extended review of the existing literature about computer capabilities, it gives the backdrop required to understand the further discussion in this thesis. To conclude, the exploration has shown that computer capabilities can perform a wide variety of human-like tasks which could lead to both a replacement of and complement to human skills in the professional work of the engineering professionals working in the construction industry in this thesis. My main argument is that the exploration in this section has shown that relations between digital technologies and human professionals have caused a change of work, and a change of skills. The former focused on a notion of automation and innovation of work activities that were susceptible being taken over by digital technologies. Regarding the latter, it was found that digital technologies can possibly perform a wide array of human skills and directly change human skill needs. The digital capabilities that can perform human skills were, for example, information processing, reasoning, physical and emotional capabilities.

2.3 Computer capabilities that can take over human work tasks

Empirical research on human skills and the digital technology driver has often focused on the replacement of jobs and “more and more tasks that once required human beings are being performed more productively, cheaply, easily, quickly, and to a higher standard by a range of systems” (Susskind & Susskind, 2017, p. 159). This captured the starting point of the focus of this thesis. For example, Elliott (2017) indicated a focus on possible changes in skill demand for workers which was based on computer capabilities compared to human work abilities through the lens of human work skills. The computer capabilities used in the research were identified in publications in computer science magazines. The researcher did this by focusing on the broad conceptualization of

information technology in which communications and robotics were also included. The research results indicated that two reasons for the disruption of skill demands were key. First, the focus was on which human abilities were reproduced with computers and second, the lower costs of computing increased their performances and as such caused a quick transformation in commercial settings. The researcher argued that it is possible to project what was found in the computer science literature before it was adopted in the economy. This projection before actual adoption in the economy was possible due to time delays and constraints for adoption. For example, the slow diffusion of technology (Rogers, 2003) and further improvements that were required to prepare the technology for use in practice. The requirements for the adoption were perceived as more intensive when the specific technology required the transformation of complex business structures "such as enterprise resource planning systems—it could take a long time for businesses to make the necessary changes to adopt them" (Elliott, 2017, p. 558) or if changes in human habits were required. Elliott used a selection of the abilities set of the O*Net database to determine the general required human work skills. After that, the abilities were compared with the IT capabilities found in the literature. The review of the computer science literature that was used was based on fourty articles in two major magazines -*AI Magazine* and *IEEE Robotics and Automation Magazine*- between 2003-2012. Elliott then aggregated abilities into four groups: language, reasoning, vision, and movement. Some of the group ratings showed different scores in their underlying abilities. For example, the group of language abilities had a difference between writing and oral expression which was not expressed in the average group rating. The researcher discussed the results in the four groups and made references to the levels for specific occupational groups and allocated a vulnerability percentage. This vulnerability percentage was to indicate the likelihood for replacement of the type of work that could be done by computer technology. This taxonomy of skills and levels was then used to define which work tasks and occupations could be replaced by technology in the future. The argument was that for those workers with a lot of tasks that are likely to get replaced, it is important to look for alternatives of human task capabilities that are not likely to be performed with, or through computers.

Table 2.

Computer capabilities , human capabilities and replacement vulnerability

	Language	Reasoning (6)	Vision (4)	Movement (4)	%vulnerable
Management	4	4	3	2	68
Engineering	4	4	4	3	36
Installation,	4	4	3	4	97
Construction	4	3	3	4	100

Note: Data adapted from Projecting the impact of information technology on work and skills in the 2030s In Warhurst et al. (2017). The Oxford handbook of skills and training

Elliot defined the first group as the human language capabilities, which consisted of listening, reading, speaking and writing. The complexity of language use in the IT capabilities was "beyond language use at the word or couple-sentence level but fall far short of language use at the lecture or book level" (Elliott, 2017, p. 565). He argued that situational and contextual judgement of the application of the language was visible in some of the articles. The computer capabilities that were found scored around a medium (4) difficulty level of the human abilities in the O*Net scales which is shown in Table 2 above.

The second group were the reasoning capabilities, which consisted of problem recognition, problem solving, developing conclusions, mathematical reasoning, and spatial reasoning. In the various articles that were examined, it was found that IT systems had difficulty executing higher levels of reasoning activities for the following reasons:

> The explanation seems to be that the knowledge required for common sense is very large but is easily overlooked because everyone shares it. Many of the reasoning systems in Table 26.3 rely on knowledge encoded in hundreds or thousands of rules, properties, or cases, whereas the necessary knowledge base for common sense appears to involve millions of elements learned over a lifetime (Lenat, 1995 as cited in Elliott, 2017, p. 567)

The quote above appears to indicate that there seemed to be a disconnection between what computer technology could do and advanced reasoning compared to human abilities. However, as Elliott (2017) suggested, recent technological systems were successful in using large amounts of information and they were able to reason within a narrow expertise focus which came close to the higher (6) difficulty levels of human abilities in the O*Net scales.

The third group were the vision capabilities, such as object recognition, feature recognition, position and space. All articles were found in the exact vision categories and integration with either the movement or language capability. The findings were defined around a medium (4) difficulty level of the human abilities in the O*Net scales.

The fourth and last ability group that the research identified were the movement capabilities, such as orientation, coordination, movement and equipment control, and body equilibrium. All IT articles that were found referred to the first three capabilities in this group, whereas only one article showed body equilibrium capabilities in IT systems. These findings were also defined around a medium (4) difficulty level of human abilities in the O*Net scales. The researcher then compared the IT capability results with the human capability results in the occupational groups which resulted in the understanding, that if human capabilities are the same or below the IT capabilities, the workers in that group are susceptible for replacement with IT in work tasks. Table 2 shows that apart from the language category, all other categories were already showing that IT capabilities can perform the same human skills as found in those occupational groups. This was particularly so for the reasoning capabilities group because the skill level in those occupations was the same or below that of IT capabilities (1st row). Elliott (2017, p. 573) indicated, "However, it is possible that the opportunities offered by new technologies will allow many of these occupations to be redefined with higher skills levels that will still require human workers." Although the research indicated a strong replacement caused by the capabilities of digital technologies in *performing* human skills, the notion of higher skill demands also indicated that a discussion about which opportunities technologies had to offer that could complement human work was required.

To conclude this section, my main argument is that the exploration in this section has shown that for a wide variety of human-like capabilities, such as those found in language and movement, digital capabilities were already able to perform these, except for the reasoning capabilities which were further away from being close to human capabilities. I believed that the notion of digital capabilities found in research surrounding job replacing discussions could be potentially used to investigate about the topic of complementing human work tasks. Despite this belief of the value of replacement research discussions, the next section will however, mainly focus on discussions found in the human work-task complementing perspective.

2.4 Computer capabilities that can complement human work.

The second relation found in the literature, more on the social aspect between computer capabilities and human work, was understood as computer technology that was changing the nature of work instead of replacing workers (Susskind & Susskind, 2017). IT and workers could work together, and the capabilities of IT could complement workers in what they were doing. Although Elliott, discussed in the previous section, seemed to focus on the relation with digital technology as work-replacing, he referred to an example of task complementing. The example was Microsoft Word software which was used among administrative staff in a "complementary way" to perform organizational work activities Elliott (2017, p. 574) and thus supported the task complementing discussion which is the focus of the exploration in this section.

Susskind and Susskind (2017) argue that professional expertise was impacted by the systems that allowed communication and storage of information and discussed this in four stages of "orality, script, print, and information technology" (p. 147). In the print and ICT stage, they argued that the available professional knowledge and its distribution was significantly more because of the channels that could be used to share the knowledge. When information first emerged in print, it had its consequences for the "quantity and complexity" (Susskind & Susskind, 2017, p. 149) of the information and the professionals that could handle these large quantities. While in the oral stage, the distribution of professional knowledge happened through the passing from specific individual to individual(s), in the script stage a selection of the professional knowledge was captured manually in written or visual word. Later, ICT and the Web transformed the creation, seeking and sharing of information, which resulted in too much information. After that, systems could even "solve problems and offer advice" (Susskind & Susskind, 2017, p. 152). Computer technology "complements workers in performing nonroutine problem solving and complex communication tasks" (Autor et al., 2003, p. 1). If the human complementary discussion is key, it requires workers to possess certain kinds of skills to work with these advanced digital technologies and it impacts the nature of other skills (Humburg & Velden, 2017, p. 205) but I would argue that at the same time they need to possess the skills that are complementary to the digital technology itself.

To conclude the section, the main claims that were emerging from the literature were the discussion of digital technology used as work-task complementary, that focused on technology understood as complementing the human skills of the professional, the task replacement that focused on which work tasks were taken over by digital technology, and skill changing where skills were required to work directly with digital technologies. The skills that were less directly associated to work

with digital technology could be impacted. The main directions in where replacement and complementary were found seemed to centre around the reasoning and administration capabilities and tasks as well as movement and vision. This then raised for me the need to know what the specific features of professionals are, who are capable of sharing in their professional work with computer technologies. Therefore, the next section in this thesis explores what humans can do and computers cannot, but first turns to a discussion about the skills associated with working with digital technology.

2.5 General and specific skills needed to work with digital technologies

The research of Humburg and Velden (2017) focused on the skillsets that graduates were expected to have to survive in today's labour market and the possible role of higher education in providing them. The researchers identified different categories of change and one of them was the ICT driver. Underneath the ICT driver, the changes and requirements for upcoming professionals to thrive were identified as well as constructs such as the skills required for knowledge and innovation management. An impact on skills to work directly with ICT but also an impact that other skills were affected was found. For example, because of the abundance of information that professionals have to use due to ICT, professionals' communication and knowledge management skills have changed. Creative skills were found, which were understood as the ability to come up with new ideas or the use of a different approach. Also identified were skills in searching for and selecting information, networking skills to receive and connect the information, and implementation skills to ensure that new innovations and information was used in the organisation. The researchers referred to the relevance of management's role in facilitating the organisational workplace to innovate and referred to those workplaces as 'high performance' workplaces. These workplaces showcased features such as a broad skills variety, teamwork, a flat hierarchy, and full responsibilities for individuals and teams. On an individual level, the professional, they argued, should have interpersonal skills with a focus on teamwork and communication, self-management to work within time and finance limitations, and strategic-organizational skills to work aligned with the broader goals of the organization.

An interesting view in the research above was that it indicated that education did not have to produce graduates with skills in all areas as the nature of work was supposed to be designed with teams consisting of individuals each with their own speciality that complemented one another. However, at the same time, the researchers argued for a basic set of skills that all graduates should have in order to thrive in the workplace that "will primarily relate to the broad academic skills that are part of the professional expertise, the ICT-related skills and the skills related to an effective *mobilization* of human resources (strategic-organizational and interpersonal skills)" (Humburg &

Velden, 2017, p. 212). At the same time, the researchers argued that it is evident that higher education is a good place to develop skills but indicated that higher education might not be a good place to develop all the skills. Apart from skills, knowledge was also required, such as profession-specific knowledge. Another interesting notion in the research was that professional expertise is associated with the development of general skills.

A doctoral thesis which connected skill development and digital technology in the context of the Arab Gulf Countries was written by Mohamed-Nour (2005) who focused on both technological change and skill development for the manufacturing sector. As part of a sponsored project, (United Nations University-Institute for New Technologies [UNU-INTECH]) the researcher did an in-depth analysis to address the causes and consequences of, and the relationships between, poor skills and technological performance. The major findings were about skill formation and the upskilling of workers and included a discussion about the poor educational system and the high percentage of uneducated foreign workers (Mohamed-Nour, 2005, p. 189). The research used both supply and demand views, micro and microdata, and firm surveys (N=44) to gather primary data. The results of the project on which this thesis was based:

> confirm the stylized facts in the new growth literature concerning the positive correlations between actual education, experience and wages and the complementary relationships between technical progress/technology (ICT), human capital/skill and upskilling (ICT training). We corroborate the importance of knowledge and the complementary relationship between tacit and codified sources of knowledge. (Mohamed-Nour, 2005, p. 190)

The research results located in the understanding of complementary relationships between tacit and codified sources of knowledge in one industry brought interesting views for the current thesis. The discussion of the skills and knowledge associated with engineering professionals appeared relevant. Although the research was closely related to this thesis because it focused on technological change and human skills and was conducted in one of the same locations as this thesis, some key features were different. A lack of focus on direct skill assessments, a lack of focus on specific work in the particular industry, a lack of focus on the individual worker and the limited learning for work notion made the research less closely connected to this thesis.

In this section, the views in research about the skills required when working with digital technology were discussed. Directly required skills and digital technology complementary skills were identified, such as communication and knowledge management skills to deal with an overload of

information (Humburg & Velden, 2017). Because workers were expected to also complement one another, not all workers would need to require the full package of skills, but a standard package was identified for each worker. This basic package included communication, self-management to deal with time and finances and strategic-organizational skills to align with broader organizational goals. Higher education was identified as a useful place to learn this basic set of skills but the need for the development of professional specific knowledge was also identified (Humburg & Velden (2017). The importance of knowledge was confirmed in another research and the complementary relationship between tacit and codified sources of knowledge was identified but then the educational system was deemed to be deficient (Mohamed-Nour, 2005, p. 189). Thus, the skills package that was discussed could vary among workers. Although skills were identified to be learnt in education, this was not the case for the related forms of codified and tacit knowledge. This implied that a separate view of skills and knowledge was required as well as a view on education and other areas where these could be learnt. This skills package argument was not specifically made about engineering, but before this thesis addresses the knowledge, skills and learning profile of the respective engineering professionals in the next chapter, the current chapter will discuss first the situation of the digital technology driver in the construction industry.

2.6 Operating with digital technologies in the construction industry

The appreciation for computer technology applications in the construction industry started in 1960 with "an optimistic view of the computer's potential as a supporting tool for design and construction" but complaints were expressed about the storage capacity, graphics and speed (Sun & Howard, 2004, p. 13). For example, research carried out between 1997-1999 in the United Kingdom in the construction industry with interviews among 403 professionals, found that 86% of them had access to a computer. CAD was mostly used as the professional software for the engineering design, but paper was still the main information exchanging mode with 91% (Sun & Howard, 2004, p. 15).

About 60 years later, most of the complaints from 1960 have been solved. The computer has become much faster, has advanced realtime graphical display and the speed has improved significantly. That means that the new technological innovations in the construction sector are now even more promising regarding increased productivity. There is, therefore, an increased likelihood of further implementation in the industry. However, these significant changes may require transformations among professionals in attitudes, skills and competencies. As can be seen in the above example on the research conducted in the United Kingdom, the availability of digital technologies did not automatically mean that they were used. People have still used traditional and

manual means. However, it has become essential for countries and firms to keep up with the technological developments in all aspects as contracting in business gets tougher, market consolidation promises to continue, and global competition within the industry grows from countries such as China, India and Korea (PWC, 2016).

In the previous chapter, it was argued that digital technologies that were associated with fuelling innovation were rapidly taking over workplaces. However, not all industries were developing at the same speed. In particular, the construction industry was often associated with lagging behind other industries regarding innovation and was considered to be relatively slow in adopting new technologies (Sun & Howard, 2004; World Economic Forum & Boston Consulting Group, 2016). Existing technologies used in new ways were identified as one of the major drivers to transform the industry in the future (Evans-Greenwood et al., 2019). For newer technologies, this was realised on a governmental level, through implementing policies and regulations for technology adoption and education, which are key pillars to ensure that the sector would quickly innovate. For example, Bhatia (2015) argued that in the situation of Dubai in the United Arab Emirates, the use of BIM was made obligatory in all government construction projects since 2013 and the regulation was amended again in 2015:

> Architectural and mechanical works for the following buildings:
> buildings that are above 20 floors
> buildings and facilities and compounds with areas larger than 200 thousand square feet
> buildings and special facilities like hospitals and universities and all similar structures
> all governmental projects
> all buildings and projects that are requested from a foreign office (Bhatia, 2015)

Although the construction industry appeared slow to adopt technologies and possibly not all firms adopted innovative or automative solutions, various technologies were available to the industry. In fact, they seemed to have already been available since 2004 as the work of Sun and Howard about IT use in the construction industry showed (Sun & Howard, 2004, p. 1). The authors indicated that the technologies were available "for a broad range of activities such as computer-aided design and drafting, building visualisation, design appraisal, project management, information storage and retrieval, cost estimating, structural analysis, on-site management". So, the argument is not that most of the digital technologies were not available but instead, the slow adoption in the industry appeared key.

One supporting argument for a reduced slow adoption is the rapid price decrease of digital technologies that occurred more recently which sped up the adoption process. That means, because of lower prices, these technologies became general technologies, and an accelerated diffusion of innovation took place. This, in turn, meant that the industry began adopting the new technologies within its general business production chain. For example, in the case of drones, prices have significantly dropped from "$100K in 2007" to "$700 in 2013". In the case of industrial robots, prices dropped from "$550k in 2007" to "$20k in 2014" which both are examples of significant price drops (World Economic Forum WEF & Boston Consulting Group, 2016, p. 9). However, once digital technology proved that it was financially worth being adopted into the business process, various benefits for business were associated with the adoption. Adoption benefits include cost reduction, improved completion time plus quality and safety improvements. For example, Gallagher (2017) argued that the likelihood of innovations in the construction industry was resulting mainly in a cost reduction of 20% in projects, and substantial improvements in the completion time of the project, as well as in quality and safety. Bower (2010), on the other hand, referred to the use of improvement in solving problems in the sector by indicating that big construction firms in Japan focused on competing with other firms by using clear technological solutions to problems in the sector, such as off-site construction by printing parts of the building components in 3-D (Susskind & Susskind, 2017). Competing with the aid of such advanced technological solutions may not (yet) apply to all countries. Developing countries need to focus first on improving the skills of their human workforce to stay competitive or use less costly digital solutions such as big data and analytics.

Sun and Howard (2004, p. 174) showed in their work for the "Strategic Forum for Construction", which was part of an initiative to accelerate change in the industry, the drivers of change enabled by computer technologies. The drivers were found in committed leadership, focus on customers, project-team integration, quality-driven agenda, and commitment to people. As a result of these, by computer technology-enabled change drivers, the following benefits for construction emerged: capital cost reduced by 10%, construction time reduced by 10%, predictability improved by 20%, defects reduced by 20%, accidents reduced by 20%, productivity improved by 10% and turnover and profits improved by 10%. This means that the previous indication by Gallagher of a 20% cost reduction was likely to be correct because a cost reduction of 10% and increased profits of 10% equals a 20% total cost reduction.

Digital technologies such as new construction technologies, automated construction equipment, and processes such as big data among the business value chain were some of the areas

identified for change. But what specific kind of digital technologies was being referred to when focusing on the construction industry? The central technological automation and innovations in the construction industry that were found in 2016/2017, were as follows:

> Mobile devices and apps
> BIM (Building Information Machine Modelling)
> Laser scanning
> Drones
> GPS tracking
> 3-D printers and robotic constructors
> Wearables (i.e. Google Glass, Virtual Reality and Augmented Reality)
> Big data and Internet Of Things (Gallagher, 2017; PWC, 2016)

What the above list of examples shows about digital technologies used in construction is that they vary from being tools or instruments, such as 3-D printers and drones, to processes such as BIM and big data. The concept of this distinction of digital technologies was discussed before in Section 2.2. According to the World Economic Forum's report on the global future of construction with the name 'Shaping the Future of Construction', the areas where the different construction technologies were used were in planning, design and engineering, construction and operations. These were divided into three layers, namely, "user interfaces and applications, software platform and control and a digital/physical integration layer" (World Economic Forum & Boston Consulting Group, 2016, p. 23). For clarity, this thesis rather refers to tools and processes, and only where necessary, explicitly refers to digital technology either being a software or a platform. Since the 2016 research was completed, there have been some digital adoption developments in the industry, but the technologies associated with full implementation in the global construction industry have not changed much. There has been progress in digital adoption in various industries and in the United Arab Emirates, these improvements are more visible than in other countries. For example, the recent developments, such as the development of the Dubai Future Academy, the development of a big data centre from IBM, and the innovative developments for the global Expo2020 exhibition highlight this.

Australia, which is a country also high on the global innovation ranking, with an overall rank of 27 on the competitive index (Schwab, 2018), showcased less visible innovation performance despite its investment on innovations for many years (Department of Industry, Innovation and Science, Australia, 2016).

Lastly, South Africa seemed to have addressed this need for innovation by implementing a couple of interventions, such as developing a specific curriculum for engineering technology which should help in educating future professionals who are capable of implementing the digital technologies in the construction industry (*Qualification Standard for Bachelor of Engineering Technology: NQF Level 7*, 2016).

To conclude the digital technological situation of the construction industry discussed above and make it clear how digital technologies in the construction industry have been applied, the next section elaborates. A discussion of the exploration follows about examples of digital technology application in the construction industry which have also formed the backdrop of the digital technologies as used in the research instruments for the sake of a stronger conceptual clarification of their use in this thesis.

2.7 Using three specific digital technologies in the construction industry

This section explores about three examples of the use of specific digital technologies in the construction industry, namely, BIM, Artificial Intelligence, and CAD. The first example of a specific digital technology found in the construction industry is BIM – or Building Information Modelling. It is often referred to as a separate category as we have seen in the previous section, but it can also be understood as a collection of more than one digital technology that uses different tools and processes. BIM can use, for example, the processes and tools of the Internet Of Things (IOT), which are basically tools that can be operated and interconnected through the internet, with or without human interference (OECD, 2015). The application found in Smart City developments is an example found in the construction industry:

> It includes objects and sensors that gather data and exchange these with one another and with humans. The networked sensors in the IoT serve to monitor the health, location and activities of people and animals and the state of production processes, the efficiency of city services and the natural environment, among other applications OECD, 2016c.(Organisation for Economic Co-operation and Development, 2017b, p. 24)

Another example of a digital technology use found in BIM was the use of predictive analytics ,which were neither tools nor software, but rather applications or processes for dealing with large amounts of data. So, multiple other digital technologies could be used in BIM. What happened in BIM was that the building-(or any other structure- was virtually modelled or simulated to improve, for example, information handling and project processes. In South Africa in particular, BIM was not

widely accepted and was often seen as a software 'tool' instead of a professional system (Harris, 2018). Researchers in the Gauteng province in South Africa found in their fieldwork among 50 engineering professionals in 2015 that 34% of them had no BIM professional experience (Kekana et al., 2015, p. 3). This research outcome based on a small sample indicated that BIM was not being implemented extensively in South Africa at the time. The 132 completed surveys conducted by the same BIM institute later in 2016 again indicated the conservative perceptions among the respondents as a limiting factor for BIM adoption in practices (Reporter, 2017). However, the systematic review of 316 peer-reviewed construction procurement articles about web-based technologies in South Africa by Laryea and Ibem (2014) seems to indicate that BIM became part of the construction procurement practice between 2001 and 2013.

In Australia, BIM was already being used among 51% of firms for 30% of their projects in 2014 according to a report from McGraw Hill Construction (2014, p. 3). However, according to a blog from the Institute of Public Works Engineering Australasia (Institute of Public Works Engineering Australasia, 2018), BIM was not mandated on a national scale. Despite that, the institute argued that the motivation was high among private sector stakeholders to stay globally competitive and BIM was included in the government's smart ICT report. In contrast to South Africa, the use of BIM among engineers is rather perceived positive and happens, although it is not being formally mandated by the Australian government.

Finally, in the United Arab Emirates, BIM adoption in the field has also experienced some delays with only 10% of the projects having used the technology (Mehran, 2016). The same author indicated the following:

> As Austyn (2014) in Middle East Economic Digest stated: 'In November, Dubai municipality announced it would be mandating the use of BIM in big projects from the start of this year. Mechanical, electrical and plumbing (MEP) and architectural work must use BIM processes on all buildings that are 40-storeys and higher, or 300,000 square feet and larger. (p. 1113)

The government mandate referred to in this article indicated that the government had taken the lead to ensure that BIM practices were being followed in the UAE and that the previous mandate of 10% in 2016 had already changed significantly. In fact, the government showcased the use of BIM in their practices during the Future Cities Show in Dubai in 2018 and seemed to support the further diffusion of BIM through various industries (*Future Cities Show Dubai*, 2018).

The second example of a specific digital technology found in the construction industry is Artificial Intelligence or so-called AI. AI is a less 'tool' based technology but more a process-based technology and can be understood as follows:

> AI can be understood as machines *performing* human-like cognitive functions. Its rapid diffusion is driven by recent strides in machine learning, an AI discipline that automatically identifies patterns in complex data sets. AI is making devices and systems smart and empowers new kinds of software and robots that increasingly act as self-governing agents, operating much more independently from the decisions of their human creators and operators than machines have previously done. AI is expected to help solve complex questions, generate productivity gains, improve the efficiency of decision making and save costs. Construction Site Robots' (Organisation for Economic Co-operation and Development, 2017b, p. 25)

The above understanding of Artificial Intelligence aligns with the understanding of computer capabilities found in a combination of the reasoning, language, vision, and movement categories as discussed in Section 2.3 which indicate a potential for both the replacement as well as the complement notion for engineering professionals. This may suggest a significant impact on the engineering professional at the individual level in terms of skills and knowledge requirements such as tacit and codified sources (see Section 2.5). Also, AI was expected to significantly impact all industries globally between 2018-2020 (Leopold, 2017, p. 6). The adoption of Artificial Intelligence as one of the newest forms of digital technology was not yet generally visible in all industries, and different countries are not at the same level of integration. An example of a country that appeared to be taking the lead in the adoption of Artificial Intelligence in its economy was the UAE. As part of Dubai's Smart Dubai Strategic Plan, this was included in their federal work practices and they have ever since made significant steps towards the adoption of AI in business. This latter point became apparent during a visit to the 'AI Everything summit' in Dubai in 2019. This conference and exhibition event showcased and discussed, the latest AI applications in industries across the globe and in particular from the UAE itself. In particular, the implementation into government services was highly visible with applications such as robot services and autonomous self-driving police cars and drones (*Artificial Intelligence Everything*, 2019). The same exhibition and conference also showcased; applications specifically found in the construction industry. For example, an AI tool that can automatically assess the condition of wall structures was implemented to make building maintenance easier. Also specific to construction, concepts used in risk management and decision-making modelling for larger construction projects, which can improve certainty, quality, speed of decision-making processes and costing were also showcased at the event. (*Artificial Intelligence Everything*, 2019).The adoption of

such sophisticated technological trends is likely to be dependent on acceptance and mindset changes in the industry (World Economic Forum & Boston Consulting Group, 2016). Innovation management and digital leadership will be essential for this process (Council of European Employers of the Metal, Engineering and Technology-based industries [CEEMET], 2016). This latter point on the importance of leadership and management facilitating the adoption of digital technologies was discussed previously in Section 2.4.

The third and last example of a specific digital technology found in the construction industry is Computer Aided Design (CAD). Using CAD means that the engineering design that was previously done by hand could now be done by sophisticated software programs such as the well-known AUTOCAD and Revit. Susskind and Susskind (2017) argued its case for architects, and I believed the same could apply for engineers working with any form of design as they both use the same design techniques although in a digital environment. The traditional advantage of digital technology relied more on the details and correcting but more advanced usage with algorithms that search for possible parameters according to design specifics already existed (Susskind & Susskind, 2017, p. 95). This latter and advanced application of CAD could change the work practice of engineering professionals radically:

> In a similar way, the arrival of 'computer aided engineering' (CAE) has transformed the work of structural engineers. Physical prototypes of a possible structure are replaced by computer simulations, and are tested with far greater rigour and precision than in the past. Advances in computational power mean that more complex, and so more computationally challenging, problems can be solved, and so more adventurous construction projects undertaken.(Susskind & Susskind, 2017, p. 95)

The above citation shows that more complexity in engineers' work is possible by using this advanced and more recent version of CAD in engineering practice. This section of the current chapter has shown that different applications of digital technologies existed in practice which may affect the practice of engineering professionals working in construction. Although a reference was briefly made to the construction industry and the engineering professional working in this industry, this thesis has not yet addressed a full account of the engineering professional. Chapter 3 is going to address the case of the engineering professional by focusing on engineering knowledge and learning.

2.8 Chapter summary

The exploration in this chapter of the thesis has explored the possible link between the general work that can be performed by humans and work that can likely be performed by using digital technology. The chapter has illustrated that there is, from an economic point of view, a connection between skills and digital technology which may result in a demand for higher-educated people. This is because they are perceived to have learnt the skills that are required to better deal with change, possess the ability to upgrade skills that may have changed under the impact of digital technology and at the same time have work tasks that are less susceptible to replacement. Next, the chapter showed an understanding about digital technologies as either replacing or complementing human work, which both had their associated consequences for understanding skills at the individual and organizational level. First, it showed that the technology could replace lower-skilled workers' tasks, and second, it might complemented higher-skilled workers in their tasks because they could use the technology in their work.

Furthermore, the chapter has addressed the idea that the concepts of automation and innovation were useful to show how technology is impacting professional work. Different understandings about computer capabilities existed, ranging from technologies that can reason like humans and are thus able to make decisions, to technologies that can perform physical human work. These both have their specific consequences for professionals' skills as either the likelihood of skills being replaced by automation, or the development of new working practices due to innovative digitalisation and the advancement of skills or complementing due to technology and its requirements. Both mechanisms are thus associated with possible changing demands for professionals' skills and may result in possible changing demands for education and training.

A connection was then made to the notion that higher educated people learnt specific skills to deal with digital technology in their work and also possessed a general knowledge base that allowed them to adapt to change, such as digital change. The skill requirements for professionals associated with the direct use of digital technology were found to be skills such as interpersonal, communication, creative, self-management, and problem-solving skills as well as codified and tacit sources of knowledge.

The chapter concluded with a brief overview of the technologies used in the construction industry, their main applications, and their adoption variances in different countries. For example, the use of design tools such as the basic versions of any CAD program was shown to be automation of

existing work practices because they made no fundamental changes to the work process. However, the advanced and recent usage of CAD in practice appeared to have the potential for more innovative power that the traditional use because the work practice changed significantly. Another example was that the chapter especially described how BIM had changed the existing work process for engineering professionals and could be regarded as a possible innovator of the engineering work practice.

This chapter has explored the possible relationships between digital technology and the work practice of professionals. The main understanding centred around task-replacement and task-complementing, which both had associated consequences for skills and knowledge. This chapter has not addressed the profile of the engineering professionals that were selected as the focus for this thesis and therefore the next chapter will do so. The next chapter will explore what is known about being an engineering professional and about the skills and knowledge that they bring along and where these are learnt.

CHAPTER 3 -WORK LEARNING RESEARCH AND ENGINEERING PROFESSIONALS

3.1 Introduction

The previous chapter showed that different relations between professionals and digital technology exist. It also showed how the construction sector is lagging in the adoption of digital technologies. This chapter explores the nature of engineering professionals and their professional features by drawing on previous workplace learning research. The main point of this chapter is that the key changes identified in workplace learning research as a field of professional learning were focused on the place of learning and the unit of learning. This chapter illustrates that both an understanding about the individual as the unit of learning and the work practice open more and different understandings about the concept of professional engineering learning.

This thesis draws on the explanatory work of Reich et al. (2015) by focusing on engineering and professional learning by using a practice-theory perspective and thereby following the five principles of practice Hager et al. (2012). This thesis thereby acknowledges, and follows contemporary beliefs about the need to focus on more than the attributes of individual learners and instead focus on both individual and practice. The individual learner attributes were understood as knowledge, skills and attitudes. In engineering work practice, interactions, materiality, opportunities and challenges were key, and the shift moved beyond technical acquisition and knowledge transfer. The move was to complex combinations of activities that were recognized as social, material, embodied and emerging (Reich et al., 2015, p. 1). The major methodological difference of this thesis compared to the research of Reich et al. (2015) is that this thesis places a focus on both learning residing in the individual and on the practice for the investigation. Therefore a discussion of the individual professionals' learning is followed by a discussion of learning residing in the practice. This thesis is also informed by the practice-theory and Actor-Network Theory as the two sociomaterial sensibilities that this thesis draws on. It thereby considered the problems identified by Trevelyan (2014 as cited in Reich et al. 2015) for engineering education as a starting point. The to this thesis relevant problems were identified as follows: engineering is more than technical problem-solving activities but socio-technical, that traditional education fails to adequately prepare engineers for work, that both humanities and social science bring strong explanatory powers for engineering practice, and that engineering practice is dependent on localized social, economic and political factors (p. 2). This thesis thereby also moves beyond the understandings of professional learning that assumes that the professional has a lack of certain skills and knowledge (Reich et al., 2015). By doing so, a broader understanding of the concept

of skills and knowledge residing in the practice was used. Research in workplace learning and professional learning, as well as research using sociomaterial theories and the skills mismatch discussion, are the main body of work that this thesis draws on. In doing this, this thesis strengthen the argument made by Reich et al. (2015) to show that a practice-theory is useful for understanding engineers' professional learning, and I add that this is specifically in a changing digital technology context. This thesis also shows that by using both the individual and the practice as the object under study, a potentially broader picture of professional learning emerged which could be used to inform policy development in engineering education and in professional learning. The use of two theoretical focuses, both the focus on the individual and the practice, was selected going forward.

3.2 Workplace learning research debates

Different traditions in workplace learning research were identified, ranging from changes about where learning occurs – education-based to workplace-based – to changes in the unit of analyses when researching workplace learning:

> We focus in particular on what aspects of professional education become visible if we shift our viewpoint from a cognitive learning perspective on professional education, which has been the dominant conceptual framework for problem-based learning, to a practice theory perspective, viewing this case of professional education as a practice, or a set of practices, in itself (Hager et al., 2012, p. 183).

Following the above quote, a distinction among learning theories appeared relevant. According to Hager (2012), they were used to distinguish between the learning theories that accompanied different understandings of professional learning over time, and in which the unit of analysis changed. The learning theories highlighted by Hager et al. (2012) were divided into three main streams, each of which had their consequences for the conceptualisation of learning and the position of humans and non-humans. Namely: (1) psychological approaches, including those of a behaviouristic and cognitive nature, in which the individual is central as the unit of learning (Dreyfus & Dreyfus, n.d.; Schön, 1983); (2) socio-cultural learning theories, in which the unit of learning has shifted from an individual to a community focus. The most well-known work is the communities of practice approach discussed by Lave and Wenger (Lave, 1991); (3) sociomaterial or the so-called Post-Cartesian (Green, 2009) theories, in which the focus on learning is understood as emergent from its context in unpredictable and unanticipated ways (Fenwick et al., 2012; Hager et al., 2012).

Given the nature of this thesis and the quest to understand the relations between materiality and professionals in work, and its relations to learning, the following were identified based on Hagers' identified learning theories. Psychological learning theories were identified as important for understanding the individual nature of learning. The behaviouristic learning theories did not reveal much about the connections to the material social world (Nicolini, 2012; Hager et al., 2012) .The socio-cultural theories, on the other hand, were more suitable for revealing the social nature of learning (Lave, 1991) among professionals. However, allowed not for an acknowledgement that materiality might had active agency in the professional work practice. Hence, the approach that acknowledged both human and materiality as having the same degree of social power, or more specifically, did not pre-define power up front, was the sociomaterial perspective. These theories further allowed for a focus on change.

In the later stream of the sociomaterial theoretical approach, learning emerged from its practice and context. It was in sociomaterial theories that learning was seen as an ongoing process which could change continuously. It was here where the strong connection between different active role-players in the practice appeared, or the so-called *actors*, whether human or non-human who were changing a practice. It was therefore not surprising that one of the theories was called '*Actor*-Network Theory' (ANT) but this theory will be discussed in Section 4.5. In addition to the terms sociomaterial and post-cartesian, other terms with the same relational materiality idea existed, whereas:

> By sociomateriality we refer to a broad arena of academic endeavor which is seeking to revalue and reconceive the role of matter and material in human practices. Many terms have been developed in recent years as a general framing for this work, including 'relational materiality', 'material semiotics' and 'new materialisms'. (Edwards & Fenwick, 2015b, p. 1385)

In educational research, it appeared that no specific theoretical strand was preferred in the sociomaterial discussion. This broader perspective of sociomateriality was adopted by Edwards and Fenwick, who argued that by using the term sociomaterial, different bodies of work were supported, such as "ANT and its many post-ANT performances, posthumanism, materialist feminism, practice-based theories, spatial theory, non-representational theory and complexity theory" (Edwards & Fenwick, 2015b, p. 1385). This flexibility, emerging from multiple bodies of work, in adopting the sociomaterial approach when researching human work practice opened the possibility of merging approaches and concepts. Combinations that were not previously done by applying a single strand of research.

3.3 The debates about the unit and place of learning

In the field of workplace learning research, viewed as a subfield of professional education, different changes had occurred. The main change had been to the unit, or object of learning. This unit of learning had changed from a focus on the individual to a focus on the community as a unit, to a more recent focus on the emergence of a network of *actors* who each formed an equal part of the network and recontextualized the learning process. In this sense, the analytical focus and unit of investigation in this thesis shifted from the individual engineering professional towards an understanding of the engineering work practice, both of which had implications for the methodological and data analysis approaches that this thesis adopted. The changes in the unit of learning were also associated with a shift in paradigms, from learning as an acquisition to learning as a participation. These paradigms were understood as a change in the metaphors of learning. Learning in the former is understood as an individual happening and a 'thing' wherein knowledge is acquired and the context loses its relevance. In the latter, it is seen as something that happens both individually and collectively with different *actors* through participation in work-related activities, such as through participation in professional practice. The quote below illustrates the practice as learning 'place':

> Even more particularly, some of these studies show that the work is not only a context, or backdrop, but is fundamentally implicated in learning (Billett, 2001, 2004; Skule & Reichborn, 2002). Yet despite some acceptance of the social and situated nature of work, professional learning is still typically accounted for, and rewarded, in individualistic terms (as cited in Rooney et al., 2014, p. 267)

If the attention was shifted from the work practice to that of preparing for, or more specifically, learning the work-practice, the focus shifted to a more conceptualised and theoretical investigated field than that of pure work-practices (Hager et al., 2012). When discussing learning, education is perhaps the first institution that comes to mind. Bills (2004) suggested that according to some vocational education sociologists, the core task of education in this area is the passing on of knowledge, in the broader sense of learning knowledge, but is not restricted to this task alone. In contrast to training, education is, a longer-term process (Bills, 2004). The same author preferred to see both education and training as one process, as the transition from generic into specific skills is "a hazy one" (Bills, 2004, p. 104). Even though, training and education were aligned, education programs were often associated with preparing graduates for work, and training was directed at keeping existing workers in work (Bills, 2014).

In general, occupational or vocational preparation for work involved preparing learners and equipping them with the skills necessary to perform in a specific occupation, vocation or profession. Usually, technical and vocational education, as a form of post-school education, was mainly responsible for equipping prospective practitioners with the knowledge, understanding and skills necessary to perform well in mid-level jobs. However, more recently, technical colleges had begun focusing on the delivery of education to this group of prospective professionals. Both involved targeting the prospective practitioners at both the post-secondary and associate degree level. The occupational or vocational way of learning which equipped learners with the skills necessary to perform in a specific profession was also seen as professional learning since preparation for professional work was the objective. In the context of engineering Heywood asked,

> given that the purpose of professional study is preparation to undertake work in a specific occupation or profession, a major question is the extent to which the curriculum prepares or does not prepare students to function satisf*actor*ily in that occupation. (Heywood, 2016, p. 8)

Heywood (2016) further reiterated that professional education constituted a form of preparation for professional practice and thus the curriculum should at least in part reflect the practice of engineers. Also, according to other researchers, it was not evident what the role of education was in features related to professional work (Nilsson, 2010), nor was there agreement about the responsible party and place that was most suitable for "learning for different kinds of skill" (Keep, 2012, p. 359). Thus, it was essential for this thesis to understand what engineering professionals do at work and indicate the relevance of professional practice for the education of potential engineers.

The main point in the discussion in this section is that I believed, resulting from the exploration about workplace learning that this thesis would benefit by keeping a focus on both the individual and the practice as the object of learning and a secondary focus on the place of learning. Three research areas were thus identified as relevant, work, skills and learning which are explored next.

3.4 Engineering work practice research interest area 1

The starting point for an improved understanding of what engineering professionals do at work in this changing digital workplace, and how people learn for work is what guided researchers to question the engineering work-practice and what it took to be a member of that specific engineering practice. "Practice is an integrating idea that links thinking with doing and people with contexts" (Rooney et al., 2014, p. 269) and where not only people are understood as important for engineering. "Engineering is

a human performance: people bring machines, tools, components, materials and information together in some pre-conceived way using engineering knowledge to produce new products or services for people" (Trevelyan, 2014, p. 40). Hence, this was a different and more contemporary conceptual approach than that implicit in the skills-mismatch discussion, which often focused on economics and the on discourse between the competences of workers and those required for a job. Trevelyan (2014) believed that using a theoretical framework for engineering practice in research was relevant for various reasons. For example, helping in decision making, understanding the practice, the objective for engineering, helping with terminology in research about engineering, facilitating standard data collection and methods, and seeing engineering practice as knowledge that needs to be built and transmitted (Trevelyan, 2014, p. 56). The arguments posed by Trevelyan showed that the quest to use a practice focus for research was relevant for understanding engineering learning for practice because it could help to understand engineering practice, individual engineering knowledge. At the same time allowed for the methodological consistency for the investigation itself.

Different fields of research have sought to research practice and were found, for example, in organizational studies, where approaches such as workplace studies, Actor-Network Theory, activity, and situated learning theory were adopted (Gherardi, 2009; Orlikowski, 2000; Nicolini, 2012; Rooney et al., 2014). In the context of educational research, the focus was also found on sociomaterial theories, such as practice-theory and Actor-Network Theory, and on researching different discourses in educational research (Fenwick, 2018; Fenwick & Edwards, 2010, 2013). Several scholars have indeed taken up the task and investigated learning for engineering practice from a contemporary perspective. For example most studies on engineering have approached the task from an industry perspective (Williams et al., 2014). However, the chapter on learning for work in Rooney et al. (2014) focused specifically on learning for engineering practice and did so primarily from an educational, rather than an industry perspective. In fact, this particular work followed the practice-based approach to find out what engineers do at work and the connections to their learning. The work suggested that workplaces or its constitutes could not anymore considered as "mere backdrops or stages where learning was occurring. Several studies thus demonstrated how work itself is not a context or backdrop but is fundamentally implicated in learning (Billett, 2001, 2004; Skule & Reichborn, 2002)". (Rooney et al., 2014, p. 268)

Although the work of Rooney et al. had not specifically investigated the connection to digital technology drivers in the context of engineering practice, it had looked into learning for the engineering work practice specifically. Concepts such as changes in workplace and learning were

discussed. The quote from Rooney et al. above shows that engineering practice was closely related to learning. Therefore, the discussion turns to engineering practice.

Engineering practice was understood as a practice that required engineers to solve technical problems for society, such as creating and constructing the physical spaces where knowledge was created. For example, engineering professionals build structures for universities and buildings for hospitals or schools. These are three physical places where knowledge creation and development take place. Some took this understanding of problem-solving further and defined it as social problem-solving practice (Heywood, 2016; Williams et al., 2014). By having looked at the scope of work of engineering practice, it became clear that engineering professionals were contributing in a significant way to society. Not only was the scope of engineering work of significance for society but the work of engineering professionals involved more than only the traditional, with engineering associated problem solving and related skills which are explored next.

3.5 Engineering knowledge, skills and capabilities research interest area 2

The concepts deployed to account for knowledge, but also skills and abilities, were often difficult to understand, as various authors defined and applied the terms differently. For example, the use of semantics was relevant for understanding all professions and highly relevant for research in general (Heywood, 2016) because it defined the linguistic and logical meaning of the words that were used. Making explicit what terms mean to prevent confusion is an insight that I acknowledged in this thesis. Terms that caused confusion in the Accreditation Board for Engineering and Technology [4], engineering criteria in 2000 included: "ability, appraisal, assessment, capability, competency, competences, criteria, criterion-referenced, evaluation, objectives, outcomes, and performance-based" (Heywood, 2016, p. 7). In more recent research, the term capabilities was identified (Wheelahan et al., 2015) but the so-called competencies have their own strong position in various educational programs and research (Heywood, 2016). Therefore, the engineering knowledge, skills and capabilities are explored next.

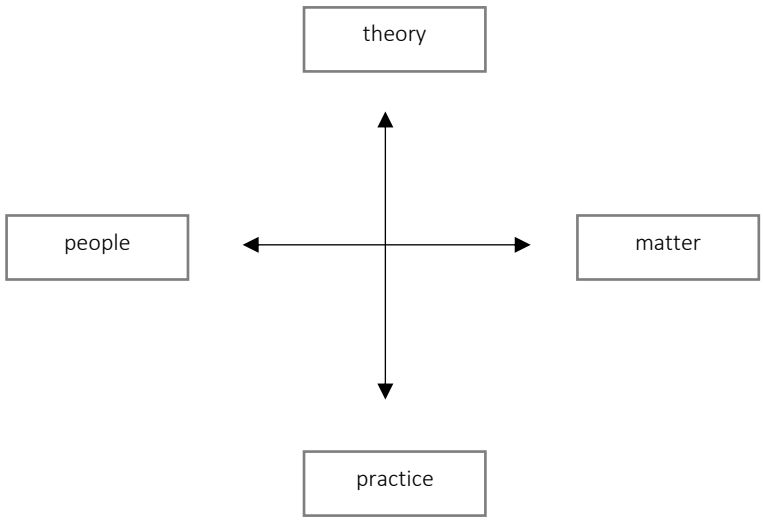
[4] Criteria for qualifications in engineering: http://www.abet.org/accreditation/accreditation-criteria/

3.5.1 Engineering knowledge.

The different terms above required a shift to the discussion of knowledge by asking, "What is the kind of knowing in which competent practitioners engage?" (Schön, 1983, p. 60). More specifically to the engineering professionals' case, what is the kind of knowing in which engineering professionals engage? Engineering professionals were involved in multidisciplinary practices where components from different knowledge dimensions were involved (Trevelyan, 2014). For example, the engineering practice dimension framework from Figueiredo (2014, p. 20) in Figure 2, identified that engineering practice consisted of four dimensions - the dimensions of, craft, design, science and social science - found in matter, people, practice and theory. The framework shows the four dimensions of practice, theory, people and matter, as all being relevant for engineering work.

Figure 2.

Engineering dimension framework simplified.



In the people category, communication as a form of social science was also important to perform the significant work engineering professionals did in practice since an engineering professional needed to communicate, not only with his co-workers and manager but often also with his clients and others, such as the regulatory role players.

When it comes to defining professional knowledge, a "very loose definition that professions are exclusive occupational groups applying somewhat abstract knowledge to particular cases" (Abbott, 1988, p. 8) seemed, to some extent, relevant to engineering professionals. Combined

engineering science, which was often used in academic programs, involved the knowledge to solve the problems of the social world. Smit (2018, p. 171) indicated that "professional knowledge has a problem-solving and task orientation as a result of the fundamental disciplinary value in engineering of responding to societal needs". The engineering accreditation guidelines in South Africa referred to this as "Engineering fundamentals: Engineering sciences that embody a systematic formulation of engineering concepts and principles based on mathematical and natural sciences to support applications" (Engineering Council South Africa, 2018, p.15) which shows a codified *translation* of knowledge into explicit units. According to the same council, the specific knowledge areas concerned with engineering were: complementary studies, computing and information technologies, engineering design and synthesis, engineering sciences, and mathematical sciences. Three of these are illustrated in the except below:

> Complementary studies: Studies that cover disciplines other than engineering sciences, natural sciences and mathematics which are relevant to the practice of engineering and engineering economics, management, the impact of technology on society, effective communication, the humanities, social sciences and other areas that support an understanding of the world in which engineering is practised.
>
> Computing and information technologies: Encompass the use of computers, networking and software to support engineering activity and as an engineering activity itself I s appropriate to the discipline
>
> Engineering sciences: Have roots in the mathematical and physical sciences and where applicable, in other natural sciences extend knowledge and develop models and methods in order to lead to engineering applications and to solve engineering problems. (2018, p. 15)

The knowledge areas for engineers in the case of South Africa defined in the excerpt above were understood as broad areas of knowledge. For example, the first category, namely, 'complementary studies' point to the entire disciplines of social science and humanities without being explicit about what kind of knowledge from those disciplines was important. The categories of engineering sciences and design were understood as disciplinary knowledge or specialised knowledge, which was also regarded as essential for engineering professionals. The need for this disciplinary knowledge received support among other researchers. For example, Sheppard et al. (2006, p. 430), suggested that "the professional education of engineers demands the acquisition of a body of specialized knowledge, problem-solving skills, and good judgment for the service of society". Allais (2012) argued that technical occupations need systematic knowledge as well as operational

experience and ability. It is in the latter reference where knowledge became visible in practice. Gamble (2003), in another branch of research, focused on technical jobs and addressed practical and scientific knowledge in the context of what was needed for technical education in craft jobs. Gamble argued that these types of practical and scientific knowledge had to inform one another. The arguments above from Gamble about practical knowledge (2003) and operational experience and ability from Allais (2012) seemed to move beyond the acquisition of individual theoretical knowledge. The move beyond the individual as the object of learning was since practical knowledge and experience assumed a practice and contextual component that moved away from knowledge that is explicit, objectified and residing in individuals. The knowledge residing in practice became visible above.

The varied discussions in this section on what individual engineering learning might include centred around different notions of competence, knowledge, skills and capabilities. The difference could be in terms of what was seen as the unit of learning. While some focused on the individual where knowledge reside, others focused on knowledge that goes beyond the individual. Going beyond this, on the one hand, there was knowledge that could be measured and transferred amongst individuals, which was defined as explicit knowledge, or, as Gamble (2003) called it, "knowledge that we can describe in words". Then, on the other, there was the knowledge that could not be described in words and made explicit. This was the so-called tacit knowledge. Eraut and Hirsh (2004) argued that the three forms of knowledge associated with professionals could be found in: situational understanding; intuitive decision making; and routine procedures. In all forms of professional knowledge, the role of tacit knowledge seemed key. The quote below shows the transformation of tacit knowledge of engineers:

> Because tacit knowledge is embodied in each individual and does not easily transfer to others (Edmondson et al., 2003; I. Nonaka, 1994; Ikujiro Nonaka & Takeuchi, 1995), it needs to be transformed into a more portable form so it can be elevated to an organisational level.(as cited in Itabashi-Campbell & Gluesing, 2014, p. 142)

While, with situational understanding, there appeared to be a mix between tacit and explicit knowledge, in decision making on the other hand, formal codified knowledge and skills were found, and lastly, in routine procedures, procedural knowledge was found to be key. The quote below shows the interdependency between tacit knowledge and explicit knowledge specific in engineering:

> A significant difference between engineering practice and engineering education is practising engineers' reliance on tacit knowledge while engineering education is based on explicit knowledge. Workplace problems often lack data and are more ambiguous compared to problems encountered in engineering education and an engineer's job is to determine "what the answer means'', "which is the best answer for all participants'' and "what is the knock on effect'' of the answer.(as cited in Goold & Devitt, 2014, p. 261)

Knowledge is socially constructed: "The foundation of engineering practice is the distributed expertise enacted through social interactions between people harnessing the formal and tacit knowledge and expertise carried by a variety of people" (Kaplan & Vinck, 2014, p. 62). For example, knowledge is constructed in practice in interactions between engineering professionals, as well as through interactions with their clients and this may vary in different cultural contexts. The complexity of the construction industry and other industries in which engineers are employed does perhaps contribute to the extensive networks in which engineers are involved. The following quote reiterates the importance of the social network for engineering practice:

> Observations of practice demonstrate that most engineering only happens in large extended networks of people: even solitary engineers need the support of many other people – technicians, suppliers, tradespeople, drafters, production supervisors and planners to name a few. Engineering itself is a social system and can only happen within an extended social context as it relies on the willing and conscientious cooperation of all these people and many others (Bucciarelli, 1988; Trevelyan, 2007). Together they construct knowledge: the knowledge of practice is created by practice. Further, the technical expertise on which engineering depends is itself distributed in the minds of the participants (Larsson, 2007; Mukerji, 2009; Trevelyan, 2010). Therefore, the social interactions between people impose further constraints on the results.(as cited in Trevelyan, 2014, p. 40)

This section has shown that the main issue at stake regarding learning understood as residing in the individual could be understood as different kind of competencies, skills, knowledge or even understood as capabilities, ranging from codified theoretical knowledge to tacit knowledge and know-how to do work. Considering the different terminology used for knowledge, the exploration turns next to the nature of skills and focus on their descriptions.

3.5.2 The nature of skills.

Globally, the concept of skills was contested and the approaches that were used to make them visible may have differed across countries because researchers in different locations may have understood the nature of skills in different ways (Payne, 2017, p. 54). Research on skills and how it was

approached depends on who was defining it (Ngcwangu, 2016). Bryson (2017) identified three approaches, each with their own constituting stakeholders and definitions: those that approached skills from a political economy perspective, and thus with a focus on economics, political science, sociology, and industrial relations; those of organisations that were found in organisational and human resource studies; and lastly, those from an educational and psychological perspective.

When investigating learning for work, the focus in organisational studies seemed to be on human resources (from a management perspective), but education appeared as the underpinning of research on workplace learning (Bryson, 2017). The relations between the different perceptions towards an understanding of skills became apparent. Education "explores how knowledge is transmitted in human society and is dominated by a pragmatic focus on teaching practice or the learning environment" and is thus "specifically focused on understanding workplaces as learning environments" (Bryson, 2017, pp. 29–30). Questions such as how people learn in the workplace, the impact on learning, what is learnt, how it is part of work processes and how to improve learning in the workplace are posed in this branch of research. The research in this thesis was therefore identified to be located in education with supplementing insights from organisational, computer technology and engineering studies. The downside of allowing for supplementing insights from other research disciplines was, that an incomplete view and understanding of the notion of skills could develop (Bryson, 2017). The reason identified was because the fields where they differ were significant, with own values and agenda's. But then, the different disciplinary research approaches broadly bring together the following:

(1) Level of focus—national, organizational, individual, and policy or personal
(2) Location of skill—in the person, the job, or a social construction
(3) Skill definitions—technical, behavioural, cognitive
(4) Type of variable—dependent or independent, mediator, or outcome

Following on from the four groups defined above, the level of focus for this thesis was identified to be the individual. The location was found in both the professional as well as the job and understood as having a dependent, independent and mediator type of nature at the same time. Research indeed showed that in specific contexts, the nature of skills was understood in narrow terms, whereas in others it was understood in a broader form. Although the dominant approach to skills over the past decades had a narrow understanding with a focus on individual competencies

(Heywood, 2016), a broader and more practice-based focus has emerged more recently. However, this practice focus was not new as the following quote for the United Kingdom landscape showed:

> Forty years ago, 'skill', when talked about in UK policy documents, mainly referred to the educational qualifications, manual dexterity, spatial awareness, and technical know-how of the skilled craft worker or technician. To be skilled was to be unionized and male, to have undergone a lengthy apprenticeship, to exert a degree of control over one's work, and to be well rewarded. (Payne, 2017, pp. 54–55)

Clarke and Winch (2006, p. 261) described skills as an individual attribute or one attribute associated with tasks and jobs, rather than one associated with broader occupations. Bryson (2017, p. 17), also described skills as an individual attribute, or "one's ability to do things", and also saw skills as being located in jobs and thus socially constructed. Winch (2013) used the term "transversal abilities", meaning the broader concepts of the application of skills needed to enable a worker to translate tasks into projects and to make individual contributions to the work in which they were engaging. "Sometimes it is best to think of skills as characteristics of individuals, and other times to think of skills as characteristics of work tasks, jobs, or even groups of workers" (Bills, 2004, p. 122). According to Bills, economists tend to see skills as an attribute of workers, while sociologists see skills in terms of jobs and the job market. The latter view is shared with Bryson (2017) and if social scientists want to measure skills in the context of the relationship between education and work, it is necessary to categorize different kinds of work skills first. Bills (2004), identified that the 'dichotomous' categories were commonly used for this categorisation: "general versus specific skills", "cognitive versus effective skills", and "basic versus advanced skills" (Bills, 2004, p. 122). This aligned well with the third category of skill definitions mentioned before.

3.5.3 Research into skills.

The exploration in the chapter turns to a discussion about the nature of skills and their importance to research. Skills are important given the interrelation between skills and knowledge or the understanding that a "skill is the ability to use one's knowledge effectively" (Layton, 1974, p. 34). Based on the assumed relation between skills and knowledge, it was important to define how skills were measured at work, and what those skills were. Even though skills development and digital technology had been researched in the past, research continued to lack a focus on individual workplace skills and occupation-specific skills (McGuinness et al., 2017), a point that was echoed in research specific to engineering education (Heywood, 2016). This has led to the selection of one professional group in one industry identified as the focus of this thesis. First, one needed to know

what was going on in the work. One way in which to do this was by using occupational classification systems. These systems were used to group occupations and define the skill types and levels required for a worker to perform the tasks associated with their work (Elliott, 2017; Handel, 2017; Lerman, 2017). Because countries could have differences in occupational systems, the International Labour Organisation developed an international classification system. Most countries either used this system directly or used it as a guideline when developing their own. The International System of Occupational Classification ISCO-08 (International Labour Office, 2012) focused on the skill levels and specialisations used for occupations and included required knowledge, tools and machinery used, materials worked with/on, and the kinds of goods produced. For example, the following was the description of a civil engineering technician and showed a fairly technical job description:

> Civil engineering technicians perform technical tasks in civil engineering research and in the design, construction, operation, maintenance and repair of buildings and other structures such as water supply and wastewater treatment systems, bridges, roads, dams and airports. (International Labour Office, 2012, p. 171).

The description for engineering level in the same civil engineering discipline varied on the degree of technical operational work because it is focused on advisory and management, as can be seen in the quote below:

> Civil engineers conduct research; advise on, design and direct construction; manage the operation and maintenance of civil engineering structures; or study and advise on technological aspects of particular materials.(International Labour Office, 2012, p. 117)

The discussion above about the use of an occupational classification system centred around a fairly general description of work that may have varied significantly among workers in different contexts and therefore a more specific measuring approach was sought for this thesis. The measurement of workers' skills had for a long time, according to Friedman (2013), been focused on human resource measurements, such as wages and educational attainment, and had not focused explicitly on measuring the job skills of workers. Friedman further argued that the early work of Autor et al. (2003) was appropriate in this endeavour. Autor et al. (2003, p. 1282) used the 'task model' to describe "how computerization affects the tasks that workers and machines perform". The model was identified as useful for analysing the extent to which changes in task composition could account for demand shifts in favour of more educated workers, which was in line with the discussion in the previous chapter about automation and innovation.

> A task is 'routine' if it can be accomplished by machines following explicit programmed rules as "nonroutine", that is, tasks for which the rules are not sufficiently well understood to be specified in computer code and executed by machines. (Autor et al., 2003, p. 1283)

Although the work-replacing discussion was not the only relation between digital technology and skills identified in Chapter 2, the task-based model was identified as useful for this thesis. Since the task-based approach functions at the occupational level and acts as a conceptual framework "that links the tasks and activities that workers perform to the skills needed to carry out these activities"(Autor & Handel, 2013, p. 60) and could be applied to investigate skill and job profiles.

The task-based approach seemed relevant when researching different occupational roles – or job-titles – together since a connection between specific work activities and skills was made. At the same time, it also allowed for a focus on digital technologies. The focus was traditionally on measuring the replacement of work-task execution by either human, conceptualised as skills, versus the execution of these tasks by automation, and centred around the discussion of technological change (Acemoglu & Restrepo, 2018). The so-called 'task-based automation' framework focused on the tasks that machines could "produce" and differed from the "f*actor* augmenting technologies" in the sense that it only focused on labour and supported the view for tasks in which labour has an advantage over automation (Acemoglu & Restrepo, 2018, p. 2). The authors further indicated that this 'task-based automation' framework could be used when studying shortages of different types of skills and automation conditions. However, it was discussed in the previous chapter that relations with digital technologies were not only task-replacing but also task-complementary, or as referred to above, "f*actor* augmenting". However, I believed that, if one was able to use the task-based automation framework to measure which tasks can be reproduced by machines, the same ideas can be used to adapt the framework so it could be used to measure task-complementary levels.

In addition to the task-based framework, another method was identified to measure skills. That of the subjective methods, such as the method applied to measure skill obsolescence. Workers are asked what skills they learned in school, whether they still use those skills, and if they feel that their qualifications are still relevant (European Centre for the Development of Vocational Training, 2010). Through these subjective methods, one should be able to assess which parts of their skills were learned in school and which parts were learned by other means, for example through workplace learning. This appeared relevant for the discussion about learning for work beyond a school focus, since the previous section on engineering knowledge had indicated that practice and experience for the development of knowledge were important for engineering professionals.

The methods that were discussed in this present section have shown that it is possible to conduct a skills investigation at the individual professional level, as well as connecting to notions of work practice and digital technology. However, none of the previously discussed methods seemed completely relevant to this thesis as they lacked a connection of the skills to the more recent specific construction industry digital technologies. Which were explored in Chapter 2. The understanding of digital skills is briefly discussed next.

3.5.4 The nature of digital skills.

When it came to the ability to work with digital technologies, digital technology skills were highlighted in most classification systems worldwide (Elliott, 2017; Handel, 2017; Lerman, 2017). For example, the technical industries in Europe referred to digital literacy skills and used the following categories: generic technical skills, such as software and hardware; programming and coding skills, such as robotics and automation programming; analytical skills, such as data handling; cybersecurity skills, such as cyber threats on the internet; and soft skills, such as cooperating, problem-solving and communicating. (Council of European Employers of the Metal, Engineering and Technology-based Industries, 2016, p. 8). Research on digital literacy may have indicated the various skills required for working with digital technologies, but the different terms often used in research made it complicated to distinguish between specific skills. For example, some of the terminology used in the field included: “Information literacy, ICT competence, 21st-century skills, computer literacy” (Covello, 2010). Although the concept was apparently challenging to define, the following definition from the chartered institute for IT might have allowed for a broad determination to frame the concept at this stage in this thesis:

> Those capabilities that mean an individual is fit for living, learning and working in a digital society. Digital literacy is about being able to make use of technologies to participate in and contribute to modern social, cultural, political and economic life (The Chartered Institute for ICT, 2013).

What appears in this discussion is that not just technical skills seemed relevant to work with digital technologies, but also more general skills. The so-called soft skills were becoming increasingly important in the handling of digital technologies and were forms of generic skills. They were ”associated with being able to learn the tasks associated with the job in the workplace, being able to adapt to new and changing circumstances and demands” (Nilsson, 2010, p. 549).

3.5.5 Keeping knowledge and skills separate for improved clarity and semantics.

The connection between skills and knowledge can become confusing. Winch (2013a) argued that it is more difficult to acquire skills at work if they are dependent on systematic knowledge, and this knowledge can only be obtained outside the workplace with the acquisition of more occupational knowledge. For example, the quote from Layton discussed before plus the following quote: "Engineering problem solving: The process of finding solutions through a conscious, organised approach that relies on the application of engineering knowledge and skills and generic competencies " (Engineering Council South Africa, 2018) indicates indeed the connections between work knowledge and skills. Therefore, based on an assumed confusion between the various concepts of skills and knowledge, I believed that future discussions had to keep both skills and knowledge separate, in order to prevent any confusion. By keeping them separate in this thesis it is thus acknowledged that they are connected and not similar.

Considering the overabundance of different terms for work-skills discussed in the previous sections, in any investigation into skills and their definitions and measurement, language semantics are crucial. For example, in the German and Dutch languages, a specific word (*fähigkeiten* and *vaardigheden* respectively) was used, which included these work abilities without being vague in the use of the term. Thus, my main argument, following on the relevance of language semantics for clarity purposes in this thesis is that a skill was understood to be something that not only resides in individual professionals but as something that goes potentially beyond the individual workers. Skills were acknowledged as possibly residing in work. It seemed from the above discussion that a broader view of skills beyond only the understanding of individual workers' skills was required. The learning of these broader skills concept is discussed next.

3.6 Professional learning for engineering practice in research interest 3

The narrow definition of skills focused on physical or manual mastery or ability -observable performance-) and de-emphasised the knowledge base of practice (Bryson, 2017). This approach is, according to (Allais, 2012), more visible in Anglo-Saxon countries, and consequently, the preparation of individuals for work was based on a much narrower curriculum, as it only focused on the preparation for specific work instead of on a general education base. One example of skills understood in the narrow definition are the so-called engineering competences, which are concerned with what the worker is potentially capable of doing but does not have to be exposed in what he does in performance (Heywood, 2016, p. 7). These competencies have been dominant in the development of educational requirements in past years (Heywood, 2016). Bills (2004) saw schooling and skills as

related but different and argued that they need to be kept separate, highlighting concerns regarding this relationship. A broader view on skills, however, moved beyond individual performance and considered learning residing in work practice:

> Indeed, even the term workplace learning emphasises the spatial dimensions of learning. Work configures opportunities for learning. As Hager and others point out, learning for work purposes has escaped the confines of the classroom. Indeed, much contemporary workplace learning literature has focused on informal learning (Eraut, 2004b; Gallacher et al., 2006; Hager, 1998; Hager & Halliday, 2006; Marsick & Watkins, 2015) – which itself draws research focus to less systematised and concrete spaces. (as cited in Rooney et al., 2014, p. 268)

In learning for work or professional learning, the purpose was identified to become an expert when having started as a "novice" (Eraut, 2004a) or to become a proficient practitioner (Hager et al., 2012, p. 7) or a professional. Indeed, after graduation, the 'novice' is embarking on his professional journey and is either involved, or not, in lifelong learning and professional learning activities that ensure that the professional becomes an expert in the practice. Eraut (2004a, p. 2) implied that there were three main reasons for embarking on this novice to expert journey, namely, "doing things better, doing things differently, or doing altogether different things". If connecting that to the perceived changing nature of work in the digital technology context, it would mean that the second of "doing things differently" or the last with "doing altogether different things" were most relevant to this thesis. In learning through practice, the main concept was that professionals learned by participating in the actual practice. That meant that purely school-based modes of learning disappeared from this discussion (Billett, 2002, 2009). How was professional learning then understood? Hager et al. (2012) argued for work-based learning which resulted in both economic and individual benefits. According to the OECD (Organisation for Economic Co-operation and Development, 2011), this was indeed the place where current and prospective employees learn most skills. For example, the work of Heywood (2016), and also Williams et al. (2014) suggested that practical engineering experience counted more than formal training and indicated that technologies were changing so fast that education was no longer able to keep pace with these developments, which could indicate the increasing importance of work-based learning.

Education might indeed not keep up with the speed of technological change, but education was identified as part of the preparing and educating professional's discussion since a general knowledge was suggested relevant for prospective professionals. According to Heywood, (2016), preparation for work for engineers needed to be informed and delivered by both industry and

education. Heywood described one initiative in the United Kingdom, the 'sandwich' structure, where students were educated in school for half of the year and worked in the industry for the other half-year for a total of four years of study (Heywood, 2016, p. 37). Similar but prevalent structures are the Universities of Applied Sciences in the Netherlands, where the curriculum is informed by industry, and 'clinical' experience is embedded in the curriculum as opposed to 'research' focused universities where no 'clinical' experience forms part of the curriculum, and neither is the curriculum informed by industry. Heywood described this dual structure as a philosophy of 'integration' as what is learned in school should inform what is done in practice and can subsequently be measured. Again, as indicated by researchers such as Heywood (2016), Hager et al. (2012), Keep (2012) together with the theory focus in school**,** the work-based practice – clinical practice – must become visible in educational preparation for work and informed by both industry and education logics. It is indeed, as was identified in the discussion before in this chapter, that the specific context of the construction industry was key for the engineering professionals. However, with the engineering work being complex and diverse and projects varied each time regarding scope, location, and role players, this context was constantly subject to change.

To understand learning in the context of change which was associated more with non-academic modes of learning such as work-based learning, a shift to a focus more on that of 'learning as a participation' was useful. Learning as a participation and learning by acquisition were regarded as learning paradigms and used as distinct categories associated with learning theories. Some argued that both were important in any discussion (Sfard, 1998). The learning modes that were associated with the participation mode where learning was seen as an ongoing process, were, for example, trial and error, using intuition and gut feeling but also learning from a colleague (Felstead et al., 2005).

Learning referred to knowledge acquisition when the cognitive theories of learning for work were followed and social knowledge acquisition when referring to socio-cultural theories:

> What might arguably be a 'socio-cultural' turn influenced researchers to look towards particular groups and relationships between people where learning at and for work were occurring, rather than take up individualistic notions from formal education. Perhaps one of the most influential ideas in this regard has been Lave and Wenger's 'communities of practice' (Lave & Wenger, 1991; E Wenger, 1996; Etienne Wenger & Snyder, 2000 as cited in Rooney et al., 2014, p. 268)

The dichotomous notions of either acquisition or participation have been used in most workplace learning research to date, following arguments made by others about the danger of

choosing one over the other (Sfard, 1998). A focus on both acquisition and participation were identified as useful in this thesis as it helped to account for the place of learning for engineering practice and at the same time allowed for a discussion about both the individual and social nature of the learning in relation to the specific engineering work context. It is the acquisition metaphor that allowed for an organizing unit to refer to the individual professional's acquisition of knowledge (knowledge gaining), after which the transfer of "a *thing* that they thereby possessed to apply as needed at some later date (i.e. transfer)" (Rooney et al., 2014, p. 267) followed. Then also, the participation metaphor allowed for a deeper understanding of knowledge building, in which both place and "sources of learning" could be identified (Felstead et al., 2005) and subsequently, the different ways of learning for the practice were understood. The "sources of learning" or hereafter referred to as the *learning modes* in the research of Felstead et al., (2005, p. 369) were as follows: (1) learning as an acquisition was identified by using the constructs of training courses paid for by your employer or yourself, drawing on the skills you picked up while studying for a qualification, using skills and abilities acquired outside of work, reading books, manuals and work-related magazines, and using the Internet; and (2) learning as a participation was identified by using the constructs of doing your job regularly, being shown by others how to do certain activities or tasks, reflecting on your performance, watching and listening to others while they carry out their work, using trial and error on the job.

However, although these categories were used in older research work, they were still applicable and relevant for this thesis. Possible learning modes that have emerged ever since, were found in the digital technology facilitated space, such as learning through online courses. The above two grouping metaphors of acquisition and participation were, according to Rooney et al. (2014, p. 267), used as metaphors and could change the perception of reality because they "assume a limited appreciation of knowledge exchange, and in doing so avoid complex understandings where new knowledge may be co-produced as a result of collective endeavours with heterogeneous others (Hager et al., 2012)" (Rooney et al., 2014, p. 267). Indeed, Boud and Hager(2012, p. 19) refer to this as a "common-sense idea…that when a professional acquires (possesses) learning, what they have learnt is inside of them (in their mind/brain for propositional learning; inside of their body for skill learning)." They challenged the common-sense understanding based on developments in neuroscience. Indeed, I believe, from a biological perspective, that the developments in neuroscience would further challenge the understandings we have about learning, but that is beyond the scope of this thesis and is a welcome and interesting avenue for my future research. Rooney et al. (2014, p. 267) referred to a further distinction within the participation model with constructing and becoming. In their

understanding of participation, they referred to “learning as a daily social practice”, in which the connection to work practice was key and moved beyond an individual worker’s competence during training. With construction, they referred to knowledge as being reconstructed in daily practice, which was context-dependent, and acknowledged the heterogenous interrelations with others involved in the practice. Lastly, with the notion of becoming, they referred to learning as an ongoing activity that happened amongst all professionals.

Alternatively, a practice, if the sociomaterial theories or the so-called post-Cartesian theories were followed acknowledged that knowledge was part of the practice. The focus was on the practice and its connected learning that could be complicated and difficult to follow, or the focus was on individual learning. In the latter, the individual knowledge constitutions to act as a role-player in that practice meant that some individual knowledge and skills were required. This seemed counterintuitive to sociomaterial theories but by embracing both understandings about the object of learning, this thesis allowed for a broader understanding beyond the use of one predefined structure.

The key claim from this section for this thesis is that learning for work was seen by some as more than an individual event and the notion of “heterogeneous” others was mentioned (Rooney et al., 2014) which implied that a network with others was involved but the focus was on human others. Also, the discussion about acquisition and participation seemed relevant because it allowed for a focus on both place and unit of learning and was identified in the learning theories as connected. Although the current work recognizes that the paradigms of participation and acquisition might not work well when describing learning for work seen from more contemporary theories such as sociomaterial theories, the value as an organizing principle for researching learning for work were identified.

The main argument of this section was that professional learning viewed from a practice-based perspective, such as which is advocated for in sociomaterial theories, required to change the perception of learning into something complicated to follow and define. The main purpose of professional learning appeared to be to improve professionally, which could be achieved through experience and skills development. The best location for this resides in the work practice itself. It was in this discussion that work-based learning became attractive, although educational preparation for engineering work was suggested in research as an individual competence event. I, therefore, understand professional learning so far as a way to prepare for this professional engineering practice and acknowledge the relevance of individual skills at the same time.

3.7 Chapter summary

The exploration in this chapter has addressed the nature and work context of the human subject of the investigation. That is, the engineering professional working in the engineering practice. The chapter has shown that engineering practice consisted of more than the application of formal knowledge. The practice was perceived as multidisciplinary where different knowledge disciplines came together, such as knowledge in craft, design, social science and science for the purpose of building the structures in society.

Next, although the chapter has shown difficulties using different terminology in research, the relation between skills and knowledge seemed to centre on the understanding that a skill is an effective application of knowledge. The task-based approach, investigating skills at the individual worker level, and the broader view on skills residing in the practice were identified as most appropriate for this thesis to investigate individual learning in a digital technology changing work context.

Furthermore, the chapter has shown that the engineering skill set includes general, technical, computer skills and soft skills which allowed them adapting to new requirements as well as enabling working with the inputs generated with digital technology. For example, digital literacy skills were important for engineering professionals to work with digital technologies directly.

Then, the engineering professional was identified as being engaged in the kind of knowing and knowledge associated with the individual and with the practice. The former has the focus on the transfer of knowledge which can be disconnected from its context. Then, the latter is where the knowledge resides in practice and is thus less easily transferred among individuals. It is associated with knowledge as participation which may happen with other people and things.

It was shown that the traditional approach to knowledge forms the backbone of education the professional bodies and the different disciplinary knowledge areas for engineering were identified. The contemporary practice approach to learning and knowledge, however, had shown possible interesting understandings about the relation with digital technology. It acknowledged that knowledge resided in a practice and was formed in relations between the activity of its members. This kind of knowledge was then understood as something that resides in a practice for which experience and participation in practice would be the ways to develop this knowledge. It is then something that

does not have to be grouped into dichotomous categories, is embodied in people, socially constructed, culturally embedded and contestable.

Learning was then described as having evolved from an individual as the unit of investigation apparent in cognitive-behaviouristic theories, to socio-cultural with a focus on groups of people, towards sociomaterial in where the relation to both human and non-human *actors* in the practice was acknowledged. The metaphors of participation and acquisition with the different associated learning modes were identified to group learning activities which were connected to learning for engineering practice. The chapter identified that the common term in contemporary theories in educational research was *sociomaterial*, which use in educational research showed that its flexible approach could open potential new insights.

The following chapter shows the backbone of the conceptual framework by addressing the selection of the approaches originating from two specific sociomaterial theories, namely, practice-theory and *Actor*-Network Theory, which were identified as the most relevant for understanding learning for work of engineering professionals in a changing digital work context.

CHAPTER 4 -
TOWARDS A SOCIOMATERIAL CONCEPTUAL FRAMEWORK FOR THE STUDY OF LEARNING FOR WORK IN A CHANGING DIGITAL WORK CONTEXT

4.1 Introduction

In Chapter 3, the different approaches to skill development and professional skills were discussed. The skills that were residing in jobs, and those that were residing in individuals were identified and the job measurement regarded as appropriate to measure the former. The chapter revealed that two major understandings of learning exist, which bring their conceptual position towards the understanding of professional work. Namely, those of understanding knowledge residing in the individual and residing in the practice. Closely connected to these different understandings in learning theories, the learning paradigms of acquisition and participation were discovered as useful organisational principles for the identified learning modes. The chapter also identified that some educational programs and professional bodies used the individual understanding of knowledge and learning, whereas sociomaterial approaches to research practice were identified to go beyond an individual focus of learning. Therefore, I believed that in engineering research, and research on workplace learning, there was a need for a broader perspective which addressed both an individual account as well as a broader perspective on the engineering practice. The need for a practice perspective was identified since previous research had indicated that engineers use both explicit and tacit knowledge, both knowing, and know-how and their knowledge may be assembled in practice. For the more explicit knowledge, this was identified to be measured by using explicit methods which were more aligned with an understanding of knowledge residing in the individual. The more tacit forms of knowledge were identified to be measured by using less explicit methods that could trace and make a broader understanding of knowledge visible, such as know-how and tacit knowledge.

So far, this thesis has predominantly focused on the engineering practice from a traditional skills perspective and only a few scholars were discussed that have adopted an account of both practice and learning from a workplace perspective. For example, it was presented that the valuable research of Reich et al. (2015) and Rooney et al. (2014) on engineering practice embarked on the journey to make some connections to learning visible, by applying the practice-theory. However, in their discussion of empirical results, they have not taken the focus on learning for practice forward beyond that point. Furthermore, although the same research had shown some connection to digital technologies used in engineers' work in the empirical findings, the focus on the digital technology

context was not foregrounded. Therefore, I believed that the empirical gap in the existing body of literature remained based on a lack of focus on both practice and the learning in the digital technology impacted work context. The argument was that by applying sociomaterial theories to research engineering learning for work in the digital technology context, the interconnections between the different research fields of work, digital technology and learning became visible and the relations between the *actors* in the network of the practice were exposed. Therefore, this chapter firstly has the aim of providing elaboration on the sociomaterial theories for understanding learning for work and secondly, to be the boundary that creates and defines the conceptual framework that was followed for this thesis.

4.2 Sociomaterial theories to make engineering learning for work visible

Researching a changing nature of work, and more specifically a digital technology context and its relations, to learning for work included more than just a discussion about the skills and knowledge of individuals. Previous discussions in this thesis about the engineering work context in the construction industry and the earlier discussion in Chapter 2 about digital technological innovations, change, and specific forms of digital technology have indicated that we do not know exactly what professionals do at work. This uncertainty about what people do at work is because often aggregated and explicit skills measures were used to define what people do at work. By using these aggregated and implicit measures, the broader understandings of knowledge and skills, by using less explicit accounts were missed. Instead, standardized job descriptions were used and the learning for work often focused on the design around competences. This may have contributed to the recent signals that this may not be correct for all workers in the context of changing digital technologies. Therefore, this thesis expands the discussion beyond a skills acquisition discussion and associated individual learning. An investigation, in which both humans and their work practice, digital technologies in work, and a connection to work and learning are included, seen from a practice-based perspective. It thus required a shift in considering what would be used to answer the research question that was discussed before. A move beyond an individual learning approach in which a focus on individual skills development was key, towards a broader focus on a network of different *actors* and connections to work, were shifting away from the psychological learning theories that saw learning as an individual activity. The move was initially towards socio-cultural theories. Learning was seen as a social activity, and participation in activities was key. It moved to sociomaterial theories and learning began to have a sociomaterial, relational and emergent nature.

The practice-theory was selected because it was helpful as a guide for investigating what was happening in the work reality (Gherardi, 2009) and the approach allowed for potentially creating detailed descriptions of work (Nicolini, 2012). Practice-theory has originated from influential work. Both Abbott, (1988) on professions and Bourdieu (1977) on practice were influential, along with more contemporary theories after the 'practice-turn' (Schatzki, 2001), such as socio-cultural (Billett, 2009; Lave, 1991) and sociomaterial practice accounts (Fenwick et al., 2012; Orlikowski, 2000; Law, 2009). The last notion of sociomaterial accounts was identified for this thesis but understood as a sociomaterial sensibility, which concept is illustrated with the quote below:

> In fact, this issue of social media in professional practice arguably deserves a more sociomaterial sensibility than it frequently receives. A 'sociomaterial' approach to understanding professionalism and learning begins with a relational orientation that brings material elements to the fore, including human bodies, objects, and technologies. Many *actors*, only some of which might be human, are recognized to be influencing what emerges as practice through their connections – perhaps particularly when those connections are mediated in virtual environments.(Fenwick, 2016, p. 667)

Then, the practice-theory was located in sociomaterial theories and therefore identified useful in adopting a sociomaterial sensibility. Therefore, the historical development of the practice-theory is briefly discussed next after clarifying the conceptual understanding of a practice-theory approach in this thesis.

Practice-theory is understood by some researchers as the "account of practices" or the place of investigation (Schatzki, 2001) and by others a "distinction between a practice, the process of practicing and the state of being practiced" (Fenwick et al., 2012) is made, or notions of "practice as epistemology" (Gherardi, 2009) exist. Others discussed the notion of professional practices (Green, 2009; Kemmis et al., 2012), occupational practices and vocational practices, professional learning through practice , participation in practices (Billett, 2002), and even pedagogic practices (Hager, 2012). Although different conceptualizations in research appeared and they were all relevant to some extent, the focus in the current discussion was mainly on the notion of the professional practice and the participating members, both human and non-human, conceptualised as *actors* in the work practice. From the different conceptualisations of practice, the notion of professional practice was key to understanding the learning for work practice of the engineering professionals in this thesis, because of the arguments made before, about an association between learning by participating in practice and the context of digital technology. Hence, I follow Fenwick et al. (2012, p. 1) and see "Professional practice as domain of vocational learning and work" to include the different

understandings of practice located in work and learning for work. Among its followers, practice-theory was not preferred to be seen as a singularity but rather a plurality, as it built forward on different traditions in research and should be seen as an ontology beyond just a theoretical lens (Nicolini, 2012, p. 13). Therefore, the decision to use two different but close related sociomaterial theories in this thesis is in line with the arguments made about using a toolbox of different theories rather than one single theory.

In this theory, the different human and non-human *actors* in the professional practice received possibly a similar power and agency, which meant that they could both potentially impact the work practice. Furthermore, the theory assumed that the relations between the *actors* in the practice happened in a non-linear fashion, which meant that there was no singular direction of a possible impact, but rather a web-like impact. It is the sociomaterial approach that is addressed in this thesis by using notions of a practice-theory and Actor-Network Theory (ANT) which will be further defined later in this chapter. The practices helped answer social questions about humans and their digital technology interactions. By adopting a sociomaterial approach, a discussion of the metaphors of learning as an acquisition and a participation were identified to help distinguish between the unit and place of learning that accompanied the quest to understand engineering professionals' learning for practice. However, this focus does not mean that the discussion about the individual nature of learning skills for engineering professionals' work in this thesis disappears. In fact, both insights were selected to be used, but the final analysis organised around the principles of the practice-theory and sociomaterial sensibilities. By applying a sociomaterial approach to understand learning for engineering practice, the practice became more than just the problem-solving and communicating activities of the practitioners involved, thus more than a focus on the engineers *performing* the practice. We can then include the human and non-human *actors* involved. These different *actors* constituted, in the case of engineering, the relationships with clients and colleagues but also with digital technologies used in this practice and other artefacts used in work. In doing this, the backdrop of adopting this approach was that the analytical attention had to shift from the individual engineer towards the engineering work practice. These were the activities involved that comprised the scope of work of the engineering professionals in question.

The practice-theory is not a single theory whose development can be described accurately and in a linear fashion. The major works that contributed to the theory's development with a focus on the notion of *actors*, relations and learning are described next. Building on the work of Nicolini, (2012) regarding the use of a "toolbox" (pp. 214–215) different theories come together to form a practice-

theory. As such, there is no single practice-theory that can be defined and explicitly stated in this section. Nevertheless, I will elaborate, and attempt to make the use of the practice-theory as explicit as possible and describe the main sources forming the backbone of my practice-theory 'toolbox' or sociomaterial sensibility.

Apart from the influences of the work of the ancient Greeks, such as Aristotle, on the terminology of *episteme, phronesis, and techne*, later and other major traditions that focused on practice and influenced the development of contemporary practice-theory research, were described in the work of Nicolini (2012). The first was according to Nicolini that Marx view focused on what people did in their everyday life and the view on knowledge as an instrument to practical mastery (p. 32). I argue, based on Nicolinis' insights about Marx's work, that his view on materialism was rather focused on the human power since it was argued that thought and the world were connected through human activity, wherein the human role was both as an *actor* and a producer. In this sense, Marx's approach failed to recognize materiality as *actors* nor as producers and would not be sufficient to answers questions in the current era. Questions about the associations between humans and the sophisticated kind of digital technologies that were identified in Chapter 2 to be closely linked and impact each other interchangeably.

Nicolini proceeded in his work with an account of Heidegger's phenomenology. He believed that "the basic ontological dimension of our being in the world is, in fact, meaningfully structured by a texture of social and material practices that remain unthought of as such, but that we more or less share in common"(p. 34). Heidegger's example of "hammering", with the carpenter's use of the hammer that was part of the carpenter's everyday world which changed and constituted his work-practice, was an excellent example of where materiality becomes part of the practice and shifts away from being a separate object. At that time, neither the agency nor the producing power of materiality was recognized but only a limited possible role of materiality was accounted for. The next account that Nicolini referred to was that of Wittgenstein. He argued that "meaning (and mind) cannot be properly conceived of as properties of individual consciousness, and instead should be conceived relationally as the result of the practical activity of sensuous and engaged agents" (Nicolini, p. 40). It was then that the relationality with materiality seemed to have taken a position in human practices in the field of those researching through a practice lens. Giddens, according to Nicolini, tried to develop a theoretical framework, in which there was a place for objects, but without being subjective. He tried to solve the issues of the relationship between "structure, agency, and the social" (Nicolini, 2012, p. 45). This time, the focus on materiality agency discussions became visible.

The view on the social, the position of the human and his producing power and the recognition of materiality's role was different among the previously discussed contributors to the development of the practice-theory. None of them recognized at the same time, the social, the context, human and non-human *actors* as the entities constituting a practice and their co-producing power. However, they all had in common that they moved away from a rationalist account of the social world for humans towards a world in which materiality became visible in our social world. They were identified as important for the current thesis because they acknowledged that materiality constituted engineering professionals' social world.

The real major shift in the use of a practice-lens for social research was based on the work of Theodore Schatzki in 2001. Schatzki initiated a work on the practice-turn in contemporary theory and advocated moving away from a social understanding in where humans were the only focus, to an account in where other *actors*, relations and embodiment came into play. His revelatory work that analysed and captured different theoretical and empirical work in social research with this approach, activated a shift in organisational research. Schatzki showed that agreement among researchers existed about the embodiment, mediation of nexuses of practices by artefacts, hybrids, and natural hybrids. Most of them saw the practice as "embodied, materially mediated arrays of human activity centrally organized around shared practical understanding" (Schatzki, 2001, p. 11). Unlike any of the previously discussed contributors that were based on the work of Nicolini, Schatzki's work fuelled a shift into acknowledging both human and non-human *actors*, becoming part of a practice, in the sense of an embodiment in activity, while at the same time acknowledging that the practice depended on the arrangement of these *actors*. It is then that the understanding moved from using a practice as a lens to a description of a practice-theory. I believed that where the former can be understood as acting as a method in research, the second can be seen as a theory where the 'toolbox' contents allowed for a broader application in research, including the data analysis, conceptualisations and application of relevant theories.

Schatzki's arguments included a focus on other phenomena when accounting for practices, wherein order was not perceived as stable but as arrangements of people, artefacts and things. The practice had to be analysed as actions that were organised by practical understandings, rules, and "teleoaffectivity" and where one had to "show how practices determine order by governing the meaning and establishments of arrangement" (Schatzki, 2001, p. 11). Schatzki's work was highly relevant to understanding the history of adopting a practice-theory as the conceptual lens in research and his conceptualisations are still useful today. Although his focus on embodiment and rules and

teleo-affectivity was extremely relevant to understanding a positioning of materiality's in engineering work practice, it did not account for a consideration of order beyond the human focus and acknowledged a possible material agency. More recent and more contemporary theories were identified that did consider the non-human *actor* as having a degree of agency and power, constituting and mediating the practice. These theories were others of the sociomateriality. Before this thesis moves to the discussion of other sociomaterial theories, the discussion of the practice-theory and the selection of a practice-theory framework relevant to this thesis is discussed.

4.3 Hagers, Lee and Reichs' five principles of theorising about practice

The practice-lens was broadly used in the 1970s for research about both the work of individuals and organisations. In fact, the approach was popular back then but lost some of its earlier popularity in later years. More recently, different researchers in the field of researching work and learning have embarked back on this focus (Fenwick et al., 2012; Hager, 2012; Reich et al., 2015). Hager et al., (2012), however, have more recently specifically looked at a practice perspective where they have aimed at developing a "conceptual framework to researching learning in and on professional practice" (Hager et al., 2012, p. 2). They developed the five principles of practice and found that "practice as knowledgeable action, as embodied and materially mediated doings and sayings, as relational, as evolved in historical and social contexts and power relations, and as emergent"(Hager et al., 2012, p. 8), was relevant to investigate questions located in the space of learning and change. Specifically, the more recent use of Hager et al. and the use of their framework in engineering research by Reich et al., (2015) had demonstrated that the practice-theory approach was relevant for research in an engineering specific context. Therefore, Hager's work is highly relevant in the sense that drawing on their conceptual framework was identified for this thesis to connect practice, learning and change.

Hager et al. (2012) followed the work of Theodore Schatzki, who was highly influential in the development of the practice-theory and its use in contemporary research. The five principles in the framework acknowledge the different streams of practice-theories, such as both socio-cultural as well as sociomaterial and its later applications. This thesis adopted the framework for theorising about practice, and it shifted the need to focus on the practice as a whole by using the five proposed principles, which stated that a practice was: (1) knowing in practice, (2) a sociomaterial phenomenon, (3) embodied and relational, (4) changing and evolving in social contexts and (5) emergent.

The first principle of practice, that of being "more than simply the application of theoretical knowledge or the product of learning"(Hager et al., 2012, p. 3), means that there was more involved

than knowledge transfer as the single unit of analysis. There was more than just applying knowledge or acquiring skills to execute single unit work tasks. It involved an understanding of knowledge that saw the knowledge as, for example, knowing in practice (Gamble, 2016b), and something that was in line with a phronesis approach (Kirkeby & Flyvbjerg, 2011). This means that knowledge became not a single transferable unit but something that emerged in practice. In this sense of a broader understanding of knowledge, I believed that only focusing on measuring the skills of individual workers was not enough to understand learning for work-practice of the engineering professionals in this thesis. This leads to the next principle of the practice framework - that practices are sociomaterial.

The second principle of practice, that of practices as a sociomaterial phenomenon, sees the practice as "sayings" and "doings" in which a practice becomes embodied (Nicolini, 2012; Price et al., 2012) and includes both human and non-human *actors*. An embodied practice means that it uses physical doings in addition to the sayings. However, some researchers have argued that embodiment also includes sayings without the physical embodiment (Nicolini, 2012). The case of engineering is multidisciplinary and engineering disciplines originally emerged from civil engineering (Figueiredo, 2014). Later the electrical, mechanical, and structural disciplines evolved from this main predecessor. Thus, subsequent different disciplines were formed that were used in any engineering team in the construction industry. So, different professional roles were involved in engineering practice but clients and sub-contractors were also key which means that the engineering practice can be understood as a social practice. It was not only human actors that were part of this practice, but also the artefacts such as building supplies, computer software, and machinery that were used by engineering professionals. These were understood as the materiality or non-human *actors* in the practice. These last two, namely socio and material, potentially formed the sociomaterial nature of engineering practice. This leads to the next principle, that practices are embodied and relational.

The third principle of practice, the practice as embodied AND relational, includes not only the sayings but also the doings in relation to each other (Green, 2009). It is then when a practice becomes a relational activity with other *actors*. The relationships between the different *actors* in the engineering practice were understood based on that they were operating in relation to each other. The relationality is visible in, for example, a multidisciplinary engineering team working on a project that align their work for the project through their interactions, communications, and meetings. The project takes place in a possible site location or office where different activities of the human *actors*

in the practice are done which can make them potentially embodied. This leads us to the next principle, that practices change and evolve in social contexts.

The fourth principle of practice focused on the fact that practices are neither stable nor are they the same. They change over time depending on the context which may also change. This context includes possible regulations and governance applicable to the practice, as well as changes in society. Thus the practices evolve over time and in different places (Hager et al., 2012b). This leads to the next and final fifth principle of the practice, that practices are emergent and evolving. This seems, more or less in line with the previous on emergent practices but Hager et al. (2012, p. 5) see practices as tacit and they are not predictable in advance but have subsequent consequences for the practitioners involved in them. So, in that case, if a work practice changes, the practitioners must change as well, and this creates an interesting concept for the changing nature of work of engineering professionals.

Specifically in engineering, with a focus on the practice-theory and professional learning, Reich et al. (2015) draw on the practice-theory theories indicated in earlier work by Hager, Lee and Reich (Hager et al., 2012) by using the five principles of practice and argued that:

> Approaches that focus on the deficits of engineers knowledge and skills will not embrace these future requirements. Rather, taking up approaches from the social sciences, in particular a practice theory perspective and the research on workplace and professional learning, can provide a new direction for engineering education research.(Reich et al., 2015, p. 20)

The quote above shows that purely focusing on discussions located in skills-mismatch discussions and notions of workers' competence was not satisfactory to address questions related to change, such as the one in this thesis: digital change. The same researchers empirically investigated engineering work practice through a qualitative study. They did this by using document studies and conducting interviews which were questionnaire focused. Thereafter, they progressed by using observations and a second round of focused interviews. They found that, based

> on recent research in the social sciences from the field of workplace learning, to suggest that a practice theory perspective on engineers' professional learning is fruitful. It shifts the focus from the attributes of the individual learner (knowledge, skills and attitudes) to the attributes of the practice (interactions, materiality, opportunities, challenges). Learning is thus more than the technical acquisition and transfer of knowledge, but a complex bundle of activities that is social, material, embodied and emerging.(Reich et al., 2015, p. 1)

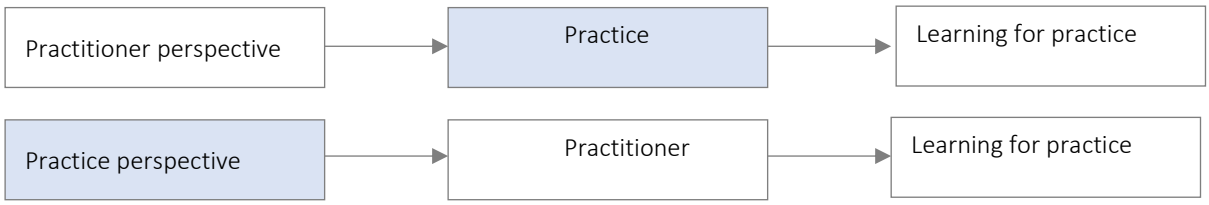
What made their research relevant to this thesis was, that they included a focus on change, although not explicitly only the change of digital technology, but more change in general. Furthermore, they highlighted a need that went beyond a focus on skills and knowledge, which appeared from the previous two quotes extracted from their publication.

4.4 Boundaries of this thesis practice-theory toolbox - taking an insider approach

In researching practice, it was important to distinguish between taking an insider or outsider approach because that defined how to approach the research (Gherardi, 2009). The insider approach takes the practitioner as the point of view, whereas the outsider view approaches the practice as the object itself. For example, in the insider approach, where the practitioner is the focus of investigation, the research is conducted "from the point of view of the practitioners and the activity that is being performed, with it temporality and processuality, as well as the emergent and negotiated order of the action being done" (Gherardi, 2009, p. 117). The insider approach shed an elaborated view of the doings and sayings of the human *actor* in the practice since the research starts with them. On the other hand, in the outsider approach where the practice itself is the unit of the investigation (Nicolini, 2012), the empirical focus is conducted from the practice itself.

Figure 3.

Connections between units of investigation, empirical, and analytical



If one would embark on an insider approach, I believed that a practitioner perspective approach was key. However, using the professionals working in the same kind of practice, could potentially lead to both a full insider approach and allowed for an outsider focus. It becomes then the practice as the unit for the analytical investigation where different other role-players, such as both human and non-human are becoming part of the investigation (Nicolini, 2012). Following the above, the focus of the unit of analysis in the investigation was required to shift between the individual professional and the practice. Therefore, the unit of empirical investigation focused on the perspectives of the individual professional, but at the same time allowed for a practice account by referring explicitly to distinct work practices. Some researchers in the field argued that a practice-theory application could only be done by physically observing the practice as a researcher (Nicolini,

2012), but others advocated for survey and interview accounts using practitioners to inform the practice view (Mulcahy, 2013). It is the latter practitioner focus that was followed in this thesis.

Another possible methodological consequence for adopting a practice-theory approach to study the engineering practice was identified. The practice had to be studied analytically rather than statistically (Nicolini, 2012, p. 14) and the focus was on descriptive and explorative research above interpretative. Therefore, the need for complex statistical techniques in this thesis disappeared and the research question and purpose should reflect this (Badenhorst, 2016).

Reference in Chapter 2.2 was made to an ontological positioning relevant in using sociomaterial sensibilities to research practice. For instance, Zukas and Malcolm (2019, p. 268) refer, drawing on the work of Mol (2002) to multiple ontologies being helpful to see the different possibilities for their research object. Since "different practices enact different objects" which allowed to show the other possibilities that could have emerged if their research object would have acted differently. Pickering (2007, p. 2) referred to an ontological vision of the world, where both human and non-humans were recognized as "open-endedly becoming" and were emergent based on a "dance of agency". He showed empirically in his investigation of two Dutch art painters that their different ontologies of human attachment and detachment of the world defined their art practice. Pickering found that the formers' paintings [de Kooning] were an emerging symmetrical interplay with the world and a product of both human and nonhuman, or 'becoming', as opposed to the strict and defined detachment of human and nonhuman in the paintings of the second artist [Mondrian] which he referred to was the "natural ontological attitude" (p. 2) for everyone in society. The relevance of his work is that he showed with examples how adopting a particular stance in the flow of 'becoming' avoids the "flow by attempting to step outside it" (p. 3) which I believed was important to consider when researching a changing work context. Important, since generalized practices and associated learning could be so since it was a tactic mistaken for the practice and learning itself, and at the same time could resist adaptation to change.

Pickering's' other example of the water engineers dealing with the outbreaks of the Mississippi river showed that the stabilized academic engineering knowledge was not enough and had to change in practice since the river followed unpredictably another route and formed side rivers which was not predicted based on existing scientific knowledge. Lastly, his example on cybernetics showed that a decentralized non-dualistic ontology appeared relevant since a diversity of relevant and contrasting fields such as artificial intelligence, robotics, management and politics had to be

merged (Pickering, 2007, p. 11). Since this thesis focus is on a changing digital context and sophisticated digital technologies were identified relevant in the construction industry in Chapter 2, I believed that adopting sociomaterial sensibilities and at the same time allowing for a focus on individual knowledge allowed me for these multiple ontologies.

The discussions of the work relevant in the above streams of work, is that thick and rich descriptions on the data were used. The sociomaterial language was used to describe how *performing* of *actors* evolved and the practice emerged in unpredictable and situated ways (Pickering, 2007, 2017; Zukas & Malcolm, 2019). Since the results could be approached with different ontologies, most of the research work in the sociomaterial streams did not move to explicit and hard findings. The research ended with the thick data descriptions and recommendations aligned with sociomaterial language. The same approaches applied in research drawing on Actor Network Theory which is elaborated on next.

4.5 Expanding this thesis toolbox with ANT to understand professional relationality

The discussion about using a practice perspective in researching engineering work was fairly general and not specific to make this thesis "toolbox" explicit enough to investigate the connections to the digital technology context and learning for work. Therefore, the conceptual framework of this thesis was drawn from a second sociomaterial theory, namely that of Actor-Network Theory, which is closely related to the first, as it maps the different *actors* in the practice and their relations. However, there is one major difference and that is the acknowledgement of the non-human agency and symmetrical nature between human and non-human in ANT.

ANT has its origins in the 1980s and was used in human-computer interaction, sociology of science and technology, and post-structuralism (Fenwick & Edwards, 2010). ANT allowed for an analytical investigation into phenomena by researching its network without predefining rules or models. What I identified as important was that this sociomaterial theoretical approach included human and non-human *actors* and it moved beyond the human focus of a practice. It moved beyond the individual practitioner, in the sense that ANT allowed for a complete network of those involved in the practice (Fenwick, 2012; Fenwick & Edwards, 2011; Gherardi, 2009; Hager et al., 2012; Orlikowski, 2000; Nicolini, 2012). ANT also moved beyond only tracing the social nature of practice, and allowed for tracing the material aspects of the practice (Fenwick et al., 2012). This made this theoretical approach highly relevant to this thesis as it shifted the focus on digital technologies as a single separate unit to something that was part of the practice and therefore the associated learning

for practice could be investigated. Other theories that used conceptions of the sociomaterial beyond the use of a practice-theory and followed conceptions of inter-objectivity were identified such as "post-structuralist geographies, complexity theory and cultural–historical activity theory" (Fenwick & Edwards, 2010, p. 2). Although these other conceptions of sociomaterial theories were acknowledged, the notion of work-practice in the application of the practice-theory and the focus on relationality in ANT was identified as most relevant to the work in this thesis.

At the same time, this feature of endorsing materiality in practice as a part of practice also attract opposition to sociomaterial approaches. Some researchers argued that materiality did not have power and was the end-result of intended human action, "apolitical" (Edwards & Fenwick, 2015b, p. 1386), and I believed that this resistance was similar to the views from Marx described before in this chapter (Nicolini, 2012). Although the ANT theory was used in research where actual agency was upfront endorsed to materiality, influential views in sociomaterial research about practice argued that no upfront agency could be endorsed to any *actor*. For instance, Latour (1996), one of the main historical figures in the development of ANT, advocated that no predefined agency should be allocated to materiality's in the first place. Therefore, this resistance to the theory in beforehand allocating power to *actors* beyond just humans might be unfounded. Unfounded, as long as no predefined agency is allocated to any of the practice members, but their actions are rather traced from the investigation which then may or may not lead to power and agency.

A second opposition to ANT-theories was identified in the application of predefined models or structures such as models of analysis and the "colonizing" of objects (Fenwick & Edwards, 2010, p. 2). The colonizing of objects goes against the nature of the ANT power to be open to any emerging features. By not taking any predefined position about the object that dominates, this resistance may become less visible. However, not defining models of analysis seemed challenging given the idea that a researcher was expected to have some ideas about the models of analysis that could be used. Also, because a research topic had been defined, some form of boundary setting, and power had already happened in this thesis. Although by defining a research objective and a starting assumption about existing digital technology and professional engineering relations, some predefined agency is already allocated in this thesis, I contend that no other predefined agency was allocated in the research.

Other resistance against adopting sociomaterial theories focused on the threat they posed to Western traditional knowledge and society structures. It challenged the existence of how we

understand knowledge and allocate what is truth. The quote below supports this view from educational research:

> Law (2011) responds to what he characterises as a 'crisis of normativity' in analysis. He argues that resistance to sociomaterial approaches emanates from their threat to deep foundational metaphysical assumptions embedded in Western or Northern common sense.(as cited in Edwards & Fenwick, 2015b, p. 1386)

The notion of traditional Western and Northern common sense is something that has been posed before by Reid and Green (2009) in the use of "standpoint" as a notion of investigating from which perspective the practice is approached. References by the same authors are made to non-Western traditions in understanding knowledge such as Afrocentric consciousness, postcolonial epistemologies, and indigenous standpoint theories (p. 9). Although these different approaches to knowledge were highly relevant and worthy of investigation, especially in the context of South Africa and the Arab World, such an investigation went beyond the scope of this thesis and would be more relevant to fit into potential future research. However, the discussion about non-Western understandings of knowledge was not the focus of this thesis. They possibly open theories that include even more *actors* beyond humans and materiality's seems relevant to argue. Especially since Western education is still the common guideline in the world. But what if this Western-associated traditional way of thinking of society has made the world less open for change by not acknowledging that we are part of a bigger universe of which different systems and *actors* are a part? Or, as Edwards and Fenwick (2015b, p. 1390) refer to Latour's views "that we have never been modern"(Latour, 1993), the development of science of nature and society was a quest in the past to be able to research them and this separation of nature, and science of society has resulted in humans being challenged in responding to urgent needs (Latour, 2004). This view about the nature of science and society being outdated, I believed, was closely related to the views in the historical work of technology as knowledge from Layton (1974) in which he discussed the view that the development of science had changed the theories about knowledge and technology, and science over time had become seen as the knowledge generator from where technology was developed. However, he believed that others had challenged this view because the technology was developed since someone designed it and put a lot of knowledge into this process, that knowledge that did perhaps not existed before. This changed the view of knowledge development and science, because it was believed to not only start with knowledge.

Despite the critiques about the agency issue concerned with materiality, I considered the sociomateriality theories relevant to the current thesis as described before. In fact, the features of Artificial Intelligence that were discussed in Chapter 2, for example, led me to believe that a change of perspective towards an understanding of the materiality as an own-operating entity could be required. This then might require humans to think about a different constitution of sociality beyond existing traditional and even current understandings of sociomaterial theories. Yet, the above assumed, in line with widespread belief, that a digital technology such as Artificial Intelligence was already able to act, do and think independently. However, less positive views existed. For example, during a presentation of the chief data scientist of IBM, Dr Muller-Stuller at the Dubai Future Academy, I came to understand that the AI developments are not (yet) so far advanced that we could call their abilities completely independent (Stuller-Muller, 2019)[5]. However, this was more a matter of time, rather than an if-question. Therefore, changing the view on some radically perceived interpretations of sociomaterial theories to understand our world might be exactly what we need to do for the future. Within this sociomaterial theoretical approach, we can distinguish other theories in addition to ANT. Namely, complexity theory, and object relations. Even though they displayed similarities on the notion of relationality between *actors* in a network of practice, the possible symmetrical digital agency focus allowed in the ANT was what makes this approach most related to this thesis.

4.6 Material agency, translation, and the capability to *enact* upon digital technology

Conceptualising a possible material agency was central to practice-based and sociomaterial discussions. The main discussion had centred around not predefining upfront agency to any *actor*. The concept that referred to this process in sociomaterial theories was called symmetry or heterogeneity. Symmetry was not seen as an individual source of empowerment but a set (Fenwick & Edwards, 2011). At the same time this has consequences for anyone or anything outside the network as the quote below describes:

> Thus, no agent or knowledge has an essential existence outside a given network: nothing is given in the order of things but performs itself into existence. (Fenwick & Edwards, 2011, p. 5)

[5] https://youtu.be/Vvyx1GMWMhk

The quote above illustrates that it was the relationality between the *actors* in the network that defined their constituting powers conceptualised as *performing* and aligns well with the view of Pickering (2007) discussed in Section 4.4:

> The point is that material things are performative and not inert; they are matter and they matter. They act together with other types of things and forces to exclude, invite, and order particular forms of participation in *enactment*s, some of which we term "adult education" and/or "lifelong learning". What then is produced can appear to be policy, or gender identity, or expertise, or a social structure such as racism. (Fenwick & Edwards, 2013, p. 53)

This *performing* is what Barad (2003, p. 803) contributed to as a post-humanist *performing,* being "not a static relationality but a doing—the *enactment* of boundaries—that always entails constitutive exclusions and therefore requisite questions of accountability". In the case of engineering, this *performing* would mean that the professional engineer had no constituting professional powers operating outside the specific work practice and their accountable actions were dependent on the practice-specific network. The relationality between the different *actors* was understood with the concept of *translation* and Law (2009, p. 144) argued that:

> To translate is to make two words equivalent. But since no two words are equivalent, *translation* also implies betrayal: traduction, trahison. Thus, *translation* is both about making equivalent, and about shifting. It is about moving terms around, about linking and changing them.

Fenwick and Edwards (2011) argued that this *translation* happened in unpredictable and undefined ways wherein the *actors* 'negotiated' their connections. It is here when the *actor* uses knowledge in a particular way which can thus feed into the *translation* process. Imagine, when a human *actor* is not capable of using digital technology in the work practice as it is supposed to work as the developer intended? This could mean that working with digital technology is restricted and cannot feed positively into the work practice. It is then in this situation that the '*translation*' will not lead to an accepted form of engineering practice. Orlikowski (2000, p. 404) indicated that by using a focus on practice, the focus allowed to examine how people "as they interact with a technology in their ongoing practices, '*enact*' [my emphasize] structures which shape their emergent and situated use of that technology". The following except from Suchman (2000, pp. 14–15) supports this view about the 'professionality' to '*enact*' upon the digital technology as it was meant to happen by the developer:

> Andrea's tutorial instructed us that rather than a simple progression from paper to CAD, the maturing of electronically based engineering practice may emerge as the informed, selective use of both paper and digital media, based on a deepening understanding of their particularities and of their effective interrelation.

It was the question of what exactly people did with technology that constituted the power of the materiality in the practice. Orlikowski (2000) argued that it is the human who is the starting point of any investigation that may want to address this question and it is the use of the technology only that can increase any advancement for human *actors* and the practice. Orlikowski (2000) conceptualised that the *enactment* could happen in three forms: (1) *Inertia* which meant that professionals use the technology to do the same kind of work as before and that their doings do not change nor do they change the technology, (2) *Application* which meant that the technology is being used to augment or refine their work so that the practice itself changes only in the light of improvements and the technology is adapted to be applied for this purpose, (3) *Change* which meant that the technology is used to improve the work practice and at the same time changes it as well as adapts the technology so that a change is visible. Orlikowski (2000, p. 423) found that the last category entailed workers from a wide range of contexts, who all had extensive knowledge about the technologies that they were working with and were also highly motivated to use it in their work and improve their practice.

A second concept that emerged was the concept of *delegation* wherein the "the ability to act at a distance through objects"(Fenwick & Edwards, 2011, p. 9) becomes visible and referred to as "immutable mobiles" in where they were mediating objects through which *enactment* between other *actors* in the network took place. This was not, however, to be understood as a digital technology with full operating responsibilities but rather as something that was used to make it happen such as electricity to power a computer, or a pen to write on paper. Although the network was unstable, it could become stabilised and it was only then that the network could be transferred or "mobilised" to another context (Fenwick & Edwards, 2011, p. 5). The *actors* had to be successfully mobilized relying on a "settlement of a series of equivalencies"(Callon, 1984, p. 14) and to "render entities mobile which were not so beforehand" (Callon, 1984, p. 14). This achievement of a successful mobilization was understood as achieving a "dynamic stability" (Scoles, 2017) ,where all *actors* came to an alignment of their activities after negotiations to reach a common goal or outcome. This stabilised form of a network is, for example, the accepted engineering practice that is embedded in regulations and frameworks for practice or a widely accepted engineering studies curriculum.

In another work by Fenwick and Edwards (2016, p. 118), a connection between practice, digital technology, and professional learning was explored by conducting literature research to develop an exploratory essay. Using literature from professionalism, professional work, education and software studies they found that: (1) despite some research on effects of the digital in educational systems,
"there has been little detailed examination of the implications of digital technologies for professional practice, responsibility and education", (2) roles are changing when digital technologies are used and other forms of challenge arise, (3) educational implications arise, (4) professionalism, professional discretion and responsibility are aspects of professional education. They take a further focus on the concepts in practices of "qualculation" and "production of prediction" and found that:

> Digital analytics and technologies are increasingly powerful and sophisticated *actors* in professional practices that are, as in the industrial revolution of the nineteenth century, transforming work knowledge, divisions of labour and work identities. However, they also bring opportunities for different forms of professionalism. They do not negate professional responsibilities and accountabilities, providing simple technical solutions to complex social issues. They do highlight the need for a more informed debate in professional education surrounding digital technologies and professional responsibility, one to which we hope this article is a small contribution (Fenwick & Edwards, 2016, p. 129).

Fenwick and Edwards (2011, p. 10) further indicated that this professional responsibility was thus the *enactment* of the different *actors* in where their transformation emerged based on the relational effects between them and where knowledge was a "property of some actions rather than others as a network becomes *enact*ed into being". However, at the same time, the work of Orlikowski (2000) which was discussed previously, demonstrated that the focus on the individual knowledge of the human *actor* made sense since they had to be able to develop the full *enactment* of the digital *actor* in the practice. It was then also a matter about the confidence of own abilities to deal with change and work with digital technologies or the locus of control.

The ANT seemed to be a flexible approach with not predefined and strict structures or methodologies to follow. However, Edwards and Fenwick (2015, p. 1389) indicated that Bruno Latour's' views were that using ANT for explanatory research did not make sense as this relied on social categories which may not make the invisible visible. This view of the inability to use the ANT as an explanatory theory did make sense in the way that only the *actors* as nodes and their relations were mapped and no meaning of the relations between them was extracted (Latour, 1996) in ANT in its purest form of use. As such, the theory cannot be described according to traditional views on a

theory. “Indeed, many of its progenitors such as Bruno Latour, John Law and Michael Callon have either struggled to avoid defining it as a set of theoretical ideas, or have distanced themselves from others’ efforts to do so”(Fenwick & Edwards, 2010, p. 2) and this was indeed visible in the three progenitors’ original work (Callon, 1984; Latour, 2005; Law, 2009). The definition of the ANT network and defining the network boundaries in traditional understandings was not what the purpose of ANT was (Fenwick & Edwards, 2011) since, by doing so the order of things (*actors*) became predefined. However, setting no network boundaries was not possible as it would let the research end in a never-ending story, and at the same time, as mentioned before, both this thesis topic and the research proposal had already defined some research boundaries.

Based on the section above, this thesis had recognized the visual power of using ANT and the concepts of symmetry, agency, and *enactment* to analyse the understandings of the relations between the human *actor* and the digital *actor* but recognized that no full account of ANT was followed in this research but rather the notion of sociomaterial sensibilities following Fenwick and Edwards (Edwards & Fenwick, 2015a, 2015b; Fenwick, 2016; Fenwick & Edwards, 2013).

4.7 The practice-theory ‘toolbox’ that guides the study

Moving forward, I had built on Miles and Huberman’s understandings of a conceptual framework in the sense that: (1) even an inductive oriented researcher knows what kind of themes are applicable in the research and can develop these based on the nature of the study and pre-existing knowledge at an early stage of the study, (2) the early groupings and their relations are redefined continuously, (3) the framework can take either a visual or textual form as long as it reflects the “constructs or variables- and the presumed relationships among them”, and finally, they can be “rudimentary or elaborate, theory-driven or commonsensical, descriptive or causal” (Miles & Huberman, 1994, p. 18). The conceptual framework indicated, according to Miles and Huberman (1994, p. 18) “who and what not will be studied” and therefore, I explain first what this thesis was addressing before I explain what this thesis was not covering. I will do this by describing in text. First, the empirical object of the study identified was the engineering professional working in the construction industry who was a member of the engineering profession. This was believed being an insider approach since it was the professional themself who was going to give their own perspectives about the learning for work of the work practice. Therefore, this thesis was empirically exploring engineering professionals’ work and learning, and the sociomaterial theories formed the basis of the conceptual framework. The practice-theory and ANT were identified as key for the investigation and analysis of the data since an understanding of the individual engineering professionals was also required. Namely, if I wanted to

answer the question about the learning for work required from the human-actors in the practice, I required to shift my focus to the learning constructs of the engineers working in the practice. So, even if the concept of knowledge was being contested and different conceptualisations existed, the relevance for professional learning was identified as being important. Professional learning ensured that workers were equipped with the appropriate knowledge foundations to be an *actor* of their work-practice. This was then done by developing the required individual knowledge and skills as well as capturing this knowledge and making it explicit.

I believed that it was therefore important for this thesis approaches to make clear what digital artefacts were used and how much digital technology was used in work tasks as being a unit of practice. It was also important to know what skills were required to be a member of this practice, and in which context was learnt for this practice, which was understood as a discussion aligned with the acquisition versus participation paradigms, where the location and place of learning became relevant. On the level of skills and knowledge, it was also important to use the participation and acquisition discussion since it allowed to analyse the empirical work. If learning as an acquisition became more apparent, it might indicate that more explicit and theoretical knowledge was required of workers. On the other hand, if learning as a participation became apparent, it might indicated that more tacit and practical knowledge was required of workers. These were both areas that were associated with engineering work in the literature discussed in Chapter 3. To operationalise these requirements for the investigation, the need for an extended skills-survey at the worker levels was identified as useful since existing surveys were not addressing all the required constructs for this thesis. The main objectives for its design were to connect a specific work practice to skills, digital technology, share of use and learning modes. Therefore, approaches followed in the skills-mismatch discussion were identified to be used to inform the design of the part of the study that was not focusing on the practice as a unit of investigation but on individual skills and knowledge. The approaches in the skills-mismatch discussion were understood as focusing on job knowledge residing in the individual and were identified as common approaches (McGuinness et al., 2017) in any discussion about workers' skills. However, the problem with only the discussion of workers' skills at the individual level appeared to be often an individual acquisition focus and no deep relational connections to other *actors* or contexts could be made.

As a second theoretical underpinning, the Actor-Network Theory was identified next to allow to see what happened at work and was then used to make the relationality of the *actors* in the practice visible in where the five principles of practice of Hager et al. were used to discuss the

relations. The focus shifted to a practice in where digital technologies were seen as essential parts of a practice, which practices were shaped with the knowledge that constituted both the engineers working in that practice and other material *actors*, and was emergent in the sense that it changed constantly. This then, I believed might shift approaches in understanding the digital technology context and its relations can be seen from a distinct perspective. Improved productivity and time improvements, as forms of doing things better under the influence of digital technology, which was discussed in Chapter 2 and 3, became thus a part of the practice. The discussion of the changing nature of work then shifts to a work practice change, which constitutes the digital technology *actors* but also the human *actors*. Underneath this focus, I believed that a discussion of the task replacement or task complementing, was key and could be used to describe the specific relationship between the human and digital *actor* in the practice.

A third relevant theoretical underpinning for this thesis was the sociomaterial approach to learning for work with a special focus on Actor-Network Theory, which aligned with the practice-theory in the sense that it also focused on the practice, recognized the different *actors* as well as acknowledged that they were emergent. The ANT approach to practice was however different in the sense that it possibly acknowledged agency to non-human *actors* who impact on one another through symmetry and *translation*. If this principle was applied to data analysis, the connections between different kind of *actors* in the practice should become visible. Another way that the relations between digital technology and professionals in learning for work could be conceptualised did exist in the form of a method to learn for professional work, also known as educational technology. Highly relevant to investigate actual learning practices in the sense of transfer and some notions of digital literacy in this body of work could be useful, this pedagogical oriented approach was however not the focus of this thesis and the focus of this research field is therefore not part of the thesis. The focus of this thesis is on the digital technologies used in work which have the purpose to be used for, or in the work practice and not on the digital technologies that have the purpose for learning practices.

4.8 Chapter summary

This chapter's purpose was to develop a conceptual framework in which the relations between a digital *actor* with possible agency and human responsibility and its consequences for learning for work became visible. First, I believed that by focusing on individual professionals from an individual insider perspective, the '*what*' of the relations between professional and digital could be explored. Second, that sociomaterial theories were useful to open an array of different perspectives and make the '*how*' of the relations between professionals and digital technologies visible. This chapter has built forward

on the existing use of applying sociomaterial theories to research work-practice. The chapter has done so by proposing its use to investigate learning for engineering professionals' work in a changing digital technology environment, in which a focus on human agency and professional responsibility were identified as key. This thesis will, therefore, take the conceptual constructs of *enactment* and *professional responsibility* forward in the discussion of results to describe the relationality between professionals and digital technology. Chapter 5 elaborates on the conceptual framework by describing the methodology that was followed for this thesis.

CHAPTER 5 -METHODOLOGY – MERGING TWO APPROACHES

5.1 Introduction

In Chapter 4, I have identified in my exploration that focusing on the individual professional, on the work practice, and on the specific driver of change, namely digital technology was possible enabled by adopting sociomaterial sensibilities in my exploration into the practice and learning of engineering professionals working in the construction industry. The conceptual framework that was identified in Chapter 4 for this thesis resulted predominantly from drawing on sociomaterial theories and was extended by including two specific sociomaterial theories to inform the empirical work and analytical analysis. For the analytical part, the practice-theory and *Actor*-Network Theory were identified to trace without any social pre-suppositions the different human and digital *actors* in the engineering work that was conceptualised as the work practice. The tracing was believed making the relations between the *actors* in the practice visible and allowed for extending the focus to both human and non-human *actors*, on the change of the engineering practices of preparing project reports and developing construction plans, and on effects for learning.

In this chapter, I position my study and set the scene for my professional case before I present the specifics about the research methodology, methods, procedures and instruments. Traditionally, methodology chapters are relatively short but detailed chapters, this is not going to be the case in this thesis as this chapter is relatively long. The reason is that different objects of learning were used in the study, a mixed methodology, the design of an own research survey and by following a sequential design. In the first part of Chapter 5, I introduce the chapter and set the scene by describing the research methodology that was used for this thesis, after which I continue with the specific design of the empirical work. The sociomaterial theories that were adopted informed the study of an *activity* or *performing* of engineering work in its own specific and unique construction context but from the standpoint of the practitioner. The study adopted a mixed-methods case-study approach to investigate empirically in two phases, the work-practice and learning for work-practice of the engineering professional. The approach used 41 voluntary participants in the surveys and 7 voluntary informants for the semi-structured in-depth interviews. However, before diving into the specifics regarding the procedures that I followed and the detailed description of the design and instruments, I turn first to the discussion about the positioning of this study. I do so by referring to educational research and learning for work traditions by addressing the consequences of adopting sociomaterial theories in research. For example, consequences such as the use of a specific

vocabulary, associated methodologies, and a particular positioning towards knowledge in sociomaterial theories.

5.2 Positioning the research

The common traditions that I found in researching learning for work seemed to focus on qualitative inquiry with the use of grounded theory, case-study, or ethnomethodology by using different instruments such as surveys, questionnaires, observations and interview instruments. Research on practice-theory often relied on observational study (Nicolini, 2012) through ethnography (Sørensen, 2009), and arguments relied on understanding that what goes beyond what can be described in words by a study subject. However, other views existed in educational research and regarded the perspective views and the standpoint of the practitioner as a trustworthy reflection of a practice (Mulcahy, 2013) and aligns well with the previous discussion in Section 4.4 about the insider approach. It is this argument of the practitioner view that was adopted for this thesis.

Major consequences of adopting sociomaterial theories and more specifically, the practice lens, are found in the philosophical traditions and epistemology/ontology discussion because a "Practice idiom is an ontological choice" (Nicolini, 2012, p. 13) and "*enact*ed from a performative ontology"(Fenwick & Edwards, 2013, p. 50). This has consequences for the understanding of the relative *reality* in this thesis. The ontology that accompanies sociomaterial theories means that the research's "nature of this reality" (Scott & Morrison, 2005, p. 85) is the understanding of a performative ontology to understand learning for work in this thesis. If "Epistemology refers to how educational researchers can know the reality that they wish to describe" (Scott & Morrison, 2005, p. 85) then an epistemological understanding is how this thesis has empirically found an answer to the question about the nature of the so-called learning for work *reality* by attending to the perspectives of the professionals themselves as the knowledge experts. However, I doubt if the choice must be between the two *truths* as sociomaterial approaches and practice-theory often rely on arguing for neither predefined boundary positioning nor adoption of strict dichotomous categories.

With acknowledging that the nature of reality of the world exists with more than human *actors* and endorsing materiality as *actors* that may act in uncertain ways which have implications for the positioning of this thesis with philosophical traditions, I position myself and this thesis in an ontological way but I adopt empirical strategies to collect appropriate data. Both the ontological positioning and the epistemological strategies to collect data are relevant since, in this thesis, the aim is to investigate a real-life human event. As Murray argues, "whatever the field of study is, evidence-

based inquiry that supports decision making driven by data, results often in conducting an empirical study" (Murray, 2017, p.25). Pring (2015), showed that the contrasts between researchers adopting quantitative and qualitative approaches rely on different notions of application and understandings about the physical and non-physical world. Pring used the contrast between the work of Hodkinson(1998) who commented on a cartesian dualism used in educational research of Tooley and Darby which was assumed that it took on positivist philosophical perspective because it contained explanations based on the physical world and quantifiable generalizations and failed the personal and social meaning nor the researchers impact. The quote below illustrates this discussion:

> Thus, in many theses and books on research, a sharp distinction is made between quantitative and qualitative research. The distinction is made on the basis not of 'appropriateness to task' but of 'epistemology' and even 'ontology'. Thus, quantitative researchers are seen to have a distinctive view about the nature of our knowledge of the physical and social worlds. And qualitative researchers question that view, and very often reject the whole quantitative enterprise as 'epistemologically flawed'. The two sorts of researcher are said to work withing 'different paradigms'.(Pring, 2015, p. 59)

Given the fact that sociomaterial theories are also described as post-Cartesian, the view in the positivist philosophical perspective does not align with this study. Nor does the view in constructivism, an approach that has received much attention in educational research. The purpose of this section is not to sketch an extensive philosophical, epistemological, and ontological review in accordance with their relating methodological selections, but rather to justify the disciplinary paradigm that forms the foundational choices of the methodology used in my study. Therefore, the focus in this study may be best positioned in the contemporary beliefs different perceived realities. This moves beyond positivist or realist accounts and even beyond constructivist accounts to more contemporary notions of post-humanism. At the same time, I shall, based on the quote above and arguments about existing distinctive views about the nature of knowledge, both acknowledge a difference between the two paradigms of quantitative and qualitative research by keeping them separate but also merging them to fit the research's "appropriateness to task".

I said before that both an individual account of professional engineers and the work practice was sought. This thesis has identified both research paradigms of quantitative and qualitative in the data collection to be appropriate to task. Thereby, I followed arguments from Pring (2015, p. 60) that both paradigms are required plus the understanding that findings are more supported and grounded (Creswell, 2009, p. 30). I believed that the use of different approaches in the empirical work aligned

well with the concept of using a toolbox in sociomaterial sensibilities that were described in the previous chapter. The aim is not to prove a point but by using analytical descriptions rather than statistical descriptions more in-depth information about the practice (Nicolini, 2012) and its human an non-human members is the result. In the focus on "description, exploration, and search for meaning" (Rudestam & Newton, 2014, p. 40), standardising becomes less important and proving or testing a theory is not the intention.

The first empirical part of the study used a focus on the individual skills of professionals to establish the object under investigation and came to results from a quantitative approach. There was pre-existing research knowledge in the form of readings for the proposal stage and this informed the design of the first part of the study. Furthermore, there was also pre-existing knowledge about what engineering professionals do in practice or know, as well as knowledge about digital technologies. This was gained (1) during my ten years as a dean of career advisory when I shadowed professionals and invited several engineering guest speakers, as well as conducted visits to the engineering departments in different universities, (2) since my own schooling in university in both biological science and science and technology education, resulted in acquiring the foundational basics of engineering science, (3) when I was directly involved as a teacher in science and technology at upper secondary school levels as well as responsible for the development and writing of the curriculum guides, (4) when I was exposed, through personal contacts, to engineering work at different professional levels front-row for over ten years. Part hereof were informal visits to engineering workplaces where I spent some time watching how the work was done. Finally (5), my major in educational technology and my interest in digital technologies and attendance of courses on programming and data science and the promise of digital technologies in education has given me a pre-existing understanding of digital technologies. The above indicates that some pre-existing knowledge about the research fields existed but the research approach is nevertheless regarded as inductive since proving a point was not the aim.

I am aware of the impact of my own underlying "values, assumptions and expectations" on the decisions that I have made in this thesis (Murray, 2017, p. 25). For example, my background in natural science and applied science might have influenced my beliefs and opinions in my research as well as my use of a specific language. This indeed became visible during the proposal and first-year report stage of the study. I had to learn a different language in the semantical sense, learn a different and less technical way of writing and had to change my beliefs about the use of qualitative data. I also had to change my understanding of knowledge from being something that can be codified and easily

described and transferred to an understanding that knowledge can also be something that resides in a practice, is *enact*ed and translated among a network of *actors* and is unstable and emergent. This journey has changed my entire worldview which has influenced my decision making and my professional and personal behaviour.

Another example is the point that I spent time at an engineering workplace which made me decide to question the need for observational inquiry in my study. This decision was made although this was discussed by some as an essential component in the practice-theory approach (Nicolini, 2012) and could potentially be perceived as a weakness of this thesis. The need was something I questioned in the sense of the attributed value associated with observations to understand the practice, in the case of my study because of my pre-existing understanding of engineering practice and my interest in the view of the insiders. Therefore, I decided to focus on the perspectives of participants, and I did not do observations.

5.3 Adopting a case-study approach to investigate practitioner reality

Restating the research questions

What is the role of digital technology for the work practice of engineering professionals' working in the construction industry - how does it relate to their professional responsibility and learning?

RQ1 Work: What do engineering professionals working in the construction industry perceive to be the key relationships between digital technology and their core professional work practices of preparing project reports and developing construction plans?

RQ2: Learning - How do digital technologies used in work, influence learning for professional responsibility of the engineering professionals working in the construction industry in the two selected core engineering work practices?

A case-study approach was used to capture the complexities and variances of both engineering professionals and the engineering practice to answer the research questions in this exploratory research. The research aim was concerned with "real world" matters with the task of "observing variables as they exist in nature" (Bordens & Abbott, 2011, p. 223), namely the human *actors* in the engineering work practice. Case-study research was selected for three reasons: (1) The case-study allowed for zooming in on one case, multiple cases and grouped cases which was useful to zoom in on

both the human *actor* and the practice itself. (2) Case studies allowed for a focus on the context which was argued as being important among researchers in the sociomaterial theories. (3) Case studies fit an exploratory approach (Murray, 2017; Saldaña, 2013) which goes along with sociomaterial approaches.

I used a sequential case-study design in both data gathering and data analysis for the study, and more accurately, a sequential exploratory approach. This means that the selected mixed methodology and case-study approach of the research were set but the sequential design in the data analysis allowed for flexibility towards emerging and unfolding concepts (Punch, 2012). These concepts contributed to the in-depth descriptive and exploratory nature. Although case studies are perceived among some researchers as a methodology to gather generalised cases, the power of case studies was regarded to go beyond only this purpose. The concept of '"extreme cases" and "forces of examples" are two examples of the use of a case-study beyond generalising based on similar cases. Flyvbjerg (2006, p. 229), reiterates that misperceptions in traditional research approaches in the selection of case-study cases are prevalent. It is his following citation that comprehensively frames my perspective about the selection of the case-study research:

> One can often generalize on the basis of a single case, and the case-study may be central to scientific development via generalization as supplement or alternative to other methods. But formal generalization is overvalued as a source of scientific development, whereas "the force of example" is underestimated. (Flyvbjerg, 2006, p. 228)

In fact, these "forces of examples" he referred to are supported from a sociomaterial theory perspective since the principles of practice as well as *Actor*-Network Theory indicated that variances in practices existed and were contestable. In addition to the "forces of example", the use of "extreme cases", I believed were good to include in case-study research since:

> Atypical or extreme cases often reveal more information because they activate more *actors* and more basic mechanisms in the situation studied.(Flyvbjerg, 2006, p. 229)

The arguments on the "forces of example" and "extreme cases" supported my selection of cases coming from different locational contexts in South Africa, The United Arab Emirates, and Australia and different professional levels. The particular case that I selected for this study was the engineering professional working in the construction industry, which can be better perceived as a grouping of different roles in a broader professional group that is closely related in the execution of daily work. For example, workers with job titles such as technician, surveyor, planner, civil engineer,

building inspector, mechanical engineering technician, environmental engineer, materials engineer, structural engineer, surveying technician, clerk of works (International Labour Office, 2012) was according to the description provided to the participating organisations. Their suitability for the research was verified by comparing the job titles provided by the companies with the job titles provided by the participants in the survey as well as confirming them with the informants in the interviews. I refer to participants and informants on purpose because in the first phase, while completing the survey, they were not informing the study in such a way that they could have changed it, which is a topic of sensibility acknowledged for in the use of sociomaterial theories.

Initially, I envisaged using workers from one large global construction organisation as this is associated to rule out other f*actors* that may influence learning for work as it provides a stable work context, but I came to realise that by (1) using a practice-theory approach to analyse work-practice, contextual differences vary, (2) engineering professionals show (international) mobility by working on different (international) projects, and (3) the discussion of extreme cases and the power of the force of example made me decide to use professionals from three different organisations and three different countries. Therefore, I decided to study engineering professionals working in the construction industry in three countries to allow for a variance in different digital technology contexts to exemplify what is common and different to be a member of the engineering practice. From a sociomaterial theory perspective, the micro and macrostructure distinction by using countries does not align well because the theory does not assume pre-defined positions in the structure of society. However, the theory does require a notion of context therefore the notion of the countries in this thesis. With the use of these distinct locations, I extended the potential variety of my cases. This variety can be described based on the different technological innovation stages of the countries which was described in Chapter 1. A variety that included more information variance in the sample to establish potential linkages between different underlying f*actors* of participants. This should, however, not be confused with the aim that exists in research of proving generalisable causal relations or conducting a comparative analysis between countries.

To conclude this section, the selected country locations that were used to gather the empirical data of the research were thus selected based on an “information-oriented selection” whereas it was envisaged to “maximize the utility of information from small samples and single cases” (Flyvbjerg, 2006, p. 230) and the information was used to develop an in-depth understanding of learning for work in the context of digital technology of the selected case of the engineering professional working in the construction industry. Therefore, I believed that by using individuals

located in different contexts and professional levels opened a range of different dimensions that goes well for a practice-theory perspective of the work engineering work practice.

5.4 Research plan and guiding questions for the study

For the first empirical phase, I selected the quantitative approach to investigate 'what' the work practice and learning constituted by conducting a survey among engineering professionals. This was done not only for data generation purposes but also to define the further focus for the qualitative part since the selection of engineering practices was established in this phase. In that sense, the research had a sequential design. For the second empirical phase, I selected the qualitative approach to elaborate on the findings of the first phase but also as "an intensive effort to understand a single unit of study within a complex context" (Murray, 2017, p. 28). In this phase, I used semi-structured interviews among a selection of engineering professionals that had participated in the first phase by posing questions in the how in the question format (Murray, 2017).

The research sub-questions of this thesis (See 5.3), reflect this *how* in the question format to explore the nature of learning for work and practice in a changing digital context and were identified to answer the main research question of this thesis (See 1.3). I divided the research into three areas of concern: work, skills and learning. These areas informed the research questions. I then developed more specific guiding questions (see APPENDIX B-GUIDING QUESTIONS RESEARCH) for each of them which were informed with primary data from the surveys and interviews, and described and explored in connection to other research. The empirical results are shown in Chapters 6 and 7. For simplicity, the two empirical data collection phases are from now on referred to as phase 1-survey phase and phase 2-interview phase respectively and I discuss the design of the survey instrument next.

5.5 Empirical phase 1 – the survey phase

The method in phase 1 consisted of the Skills Technology Work Learning survey (STWL-survey) among individual engineering professionals of the selected case. The STWL-survey was developed for the purpose of this thesis, see for the elaboration of the survey APPENDIX C-STWL DESIGN and APPENDIX D-STWL-SURVEY for the survey. Participation was voluntary and without incentive, and the prospective engineering professionals working in the construction industry were informed through their large private organisation. The organisation consented first to participate (see APPENDIX E-CONSENT LETTER AND FORM COMPANY) and I distributed the invitation and guidelines among their employees. All participating organisations selected a sample of workers that fitted the provided description of engineering professionals, where after I approached them directly by sending them the

formal invitation letter (See APPENDIX F-PARTICIPANT INVITATION SURVEY) and a direct survey invitation with the Qualtrics link on their work e-mail. All procedures were for all countries followed with carefulness as submitted for my ethical clearance (See APPENDIX G-ETHICAL CLEARANCE APPROVAL) and participants received again an information letter directly in the survey and had to give their consent before they could proceed. Strategies were used that were associated with higher response rates such as including a cover letter and considerations about the design of questions (Wilkinson and Birmingham, 2003).

The final sample was disappointing and unexpected since different sampling strategies for gathering companies had been used with extensive efforts which resulted in various positive initial confirmations but no following up. Different strategies were used, such as using search engines to locate larger private construction organisations, e-mail invitations and even approaching the managing directors and CEO's of the companies on LinkedIn which resulted in some refusals and some initial approvals. Eventually, various sources of personal contacts and the help of professional bodies resulted in the initial direct contact with the participating organisations who eventually contributed to the final sample after a lengthy process of months.

The digital distribution of the self-reported survey among the 92 engineering professionals working in the three different firms in the three different countries resulted in a final sample of 41 engineering professionals between October 2018 and January 2019. The sample consisted of about two-thirds of technical and engineering professionals and one-third managing professionals. The actual sample size N=41 compares to a success rate of 44.6% after 39 (42.4%) non-responses and 12 (13%) incomplete surveys were removed from the data sample. The reason for the relatively high number of uncompleted surveys is that the survey was lengthy, and it took time to complete. However, the uncompleted surveys were often not progressed after the first couple of minutes although the indicated 20-minute time for completion was indicated in the introduction. This envisaged completion time was found by testing the survey and expert feedback in the Qualtrics software and aligned with the maximum time for a positive impact on response rates (Wilkinson & Birmingham, 2003). I therefore question the 20-minute as a suitable time for professionals in a fast-paced industry since Chapter 1 has shown that they are operating in a demanding industry. Although all these strategies for improved response rates and reliable data were followed, it took me several months to get access to participants and negotiate the potential sample with the companies. It then took significant time and effort to get the completed surveys back from the participants and significant time to clean and analyse data which is discussed next.

5.6 Data analysis procedures

The associated advantages of survey instruments with easy analysis and being inexpensive (Wilkinson & Birmingham, 2003) were not relevant in my case since I used a complicated design and this created complications for the data analysis as well. I used the software Qualtrics as a survey design and management tool since it created more advanced design options than the free survey software options available, then it also created difficulties once the completed survey results were in. The in-program options for data generation in the software appeared to be too basic for my survey analysis and I proceeded by purchasing IBM SPSS Statistics Edition 25. The connections I made in the *STWL-survey* provided an extra challenge in considering how to clean and transform the data so that it was useful. Specifically, the software automatically generated multiple binary variables from one intended categorical nominal variable, and I ended up with around 2100 different variables in my raw dataset. This was an example of my lack of program specific digital capabilities to fully and professionally utilise the SPSS software as was meant by its developers to benefit my research practice and my own lack of full *enactment* upon SPSS. So, the initial envisaged timeframe to clean the data tripled in time. This issue with the significant number of variables also resulted in the need to develop new codebooks since the original developed codebooks were no longer useful. This resulted in the rewriting of the codes in an applicable format and I opted for using the SPSS syntax for the benefit of allowing for transparency of the procedures that I followed but also to ensure potential replicability of the research. If someone else would apply the SPSS-syntax codes to the data, the same result would appear whereas explaining the steps that were taken in SPSS can get confusing and replication might not be possible (See APPENDIX H-DATA GENERATION PROCEDURE IBM-SPSS-25).

The analytical instruments used in phase 1 were as follows: IBM's statistical software SPSS edition 25 for data cleaning and transformation as well as generating the descriptive statistics and cross analysis required for the analysis; Microsoft Excel Office 10 as a support system, back-up and control system to supplement the SPSS software but also to further amend tables and graphics based on the raw data generated with IBM-SPSS-25. The first step in the data generation procedure was to clean the raw survey data and create a usable format in IBM SPSS-25 (See for an elaborated account APPENDIX H-DATA GENERATION PROCEDURE IBM-SPSS-25). Thereafter, I used a systematic approach to analyse the data by focusing on the three areas of concern that were identified for the empirical work (work, skills and learning). The headings of the survey came from O*net and formed the basis on which to develop my coding (Scott & Morrison, 2005) and in my analysis of the data.

Further analysis for data generation was done by using SPSS syntax. The purpose of the data of this research phase was two-fold, namely, to explore the data and generate the ideas for the design of the second phase of the study and to analyse the research constructs quantitatively. Two core engineering work tasks were selected based on these results to proceed with in empirical phase 2 (see APPENDIX I-DEFINING AND SELECTING THE CORE WORK PRACTICE). Therefore, the unit of analysis of the data in the final format in this first phase of the study was two-fold: 1, The workers were treated as individuals but described as one group N=41 to define the further focus on the top work tasks and 2, Through cross-tabulation in SPSS-25, the results generated from specific work tasks were extracted and work-practice specific professionals identified. The final and cleaned data sample included 16 professionals from Australia, 17 from South Africa, and 8 from the United Arab Emirates. The engineering professionals were separately analysed but also aggregated into three professional groups which resulted in 8 technical professionals, 20 engineering professional, and 13 managing professionals which is shown in Table 3.

Table 3.

Frequency of professional groups in STWL-survey

Aggregate professional group based on jobtitle respondent

		Frequency	Percent
Valid	Technical Employee	8	19.5
	Engineering Employee	20	48.8
	Managing Employee	13	31.7
	Total	41	100.0

Note: The above data is the distribution of professional groups. Computer capabilities connected to human capabilities and replacement vulnerability. Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The aggregation of the engineering professionals into three professional groups was done based on the respondents' respective job titles. Namely, every professional with a job title that included leader, manager, director or executive was aggregated into the managing group. Every professional with a job title that used technician, site agent, assistant engineer or technologist was divided into the technical professional group and lastly, everyone that had a full reference to engineer in the job title was aggregated into the engineering professional group. For example, the digital technology mastery of respondents aggregated into their professional groups was derived by using the syntax in IBM SPSS-25 shown in Figure 4.

Figure 4.

SPSS-25 Syntax code for digital mastery by professional group

IBM SPSS-25 SYNTAX CODE

```
SUMMARIZE  /TABLES=Digitech_BIM_Mastery  BY  Digitech_Prepare_BIM by Digitech_BIM_Mastery by
Occupational_Group       /FORMAT=LIST   /TITLE='Case Summaries'   /MISSING=VARIABLE   /CELLS=count.
```

I constructed the results of the quantitative data section by: (1) using descriptive statistics and following individual knowledge understandings about learning for work and cognitive approaches to knowledge; (2) using the visual representational power of correspondence analysis and perceptual maps in IBM SPSS-25 software to make the relations between the different constitutes in the practice and connections to the digital visible; (3) using cross-reference tables in the IBM SPSS-25 software to show associations between skills and knowledge, and learning, as well as between knowledge and skills. A thematic but data-driven analysis was done by using a contrasting approach based on professional levels and countries. IBM SPSS-25 software and Microsoft Excel were used to develop the analysis and visual representations in the quantitative results chapter.

5.7 Empirical phase 2 and the data collection and procedures

The second part of the empirical work, the semi-structured interviews, was conducted between May 2019 and July 2019 with eight engineering professionals who also participated in the survey during phase one. The composition of the sample was similar to the survey sample in the sense that workers from different job-levels, engineering disciplines, and about one-third of managing professionals and two-thirds of technical/engineering professionals were part of the sample. Another interesting feature is that all the informants had either selected the work-practice *preparing project reports* or *developing construction plans* in their survey under the top-5 daily work tasks. I decided to focus on

these during the interviews to make the data collection through the interview more focused and explicit to a specific engineering practice. The qualitative data collected for this thesis included interviews with 8 engineering professionals of which 5 were from a medium-developed country and 3 from a well-developed country. The professional engineering levels that constituted the interview sample were as follows:

Well-developed context

- 1 engineering professional focusing on the work practice of developing construction plans
- 1 engineering professional focusing on the work practice of preparing project reports
- 1 managing professional focusing on the work practice of preparing project reports

Medium developed context 1

- 1 technical professional with some professional responsibilities in engineering focusing on the work practice of preparing project reports *
- 1 technical professional with some professional responsibilities in managing in the work practice of developing construction plans

Medium developed context 2

- 2 engineering professionals with some professional responsibilities in managing focusing on the work practice of preparing project reports
- 1 technical professional with only technical responsibilities focusing on the work practice of preparing project reports

The interview in a medium-developed context, unfortunately, had to be removed from the sample because the interview was never completed after the first appointment and start of the interview. Therefore, the partial results from this interview were invalid. Following the consent process (see APPENDIX J-CONSENT INTERVIEW INFORMANTS), I asked the participants by e-mail for suitable days and times plus their preferred medium. All planning and development steps were recorded in an interview-protocol book, specific for this phase of the research.

The procedures followed for the interview phase were as follows: Before the first interview started, all interview question templates were developed based on the template depicted in APPENDIX K-INTERVIEW PROTOCOL TEMPLATE. The interview template was developed based on the insights discussed in Section 4.7 to include the focus on the practice-theory. The principles of the practice were included in the interview template by focusing on both human and non-human *actors*

as well as incorporating a notion of context as well as the notion of change in the guiding questions about the work-practice. Then, the informants' personal survey results were extracted, and relevant skills, knowledge, digital technology indicators and learning sections transferred to their individual interview protocol for allowing survey verification. I listened to each audio recorded interview, evaluated the interview and checked if anything in the interview came up that would require extra focus in the next interview allowing for in-depth discussion and focus in the interview. After each interview, I did the transcription manually.

I decided to opt for the NVIVO-12 software to further analyse the content within the broader context of the research which allowed me "to move beyond word counts to consider such issues as the relationship between words and phrases" (Wilkinson & Birmingham, 2003, p. 68). However, the steep learning curve of NVIVO 12 made this task significantly more time intensive and I decided to not rely too much on the software programme for the analysis and I predominantly used Excel for this purpose. This is an excellent practical example of a failed *translation* and inability from my professional capability to fully *enact* upon the digital technology for my professional research practice which I described before since the professional inadequacy from me as the researcher to use the software as is meant by the developers might have impacted my own research practice and thus might have impacted the results in this study.

I initially organized according to the five principles of the practice-theory and read multiple times for preliminary analysis. An analysis was done on broader parts of the text in a narrative format and case reports of each professional generated (See APPENDIX L-DATA GENERATION INTERVIEW 5 PRINCIPLES). At a later stage, another coding cycle was started to move beyond the themes that were selected based on the five principles of practice framework and search for more meaning in the data. This second round of coding was then done by following 3 steps (See for the description of the steps, APPENDIX M-INTERVIEW CODING PROCEDURES) and examples of the resulting codes are shown in Figure 5.

Figure 5.

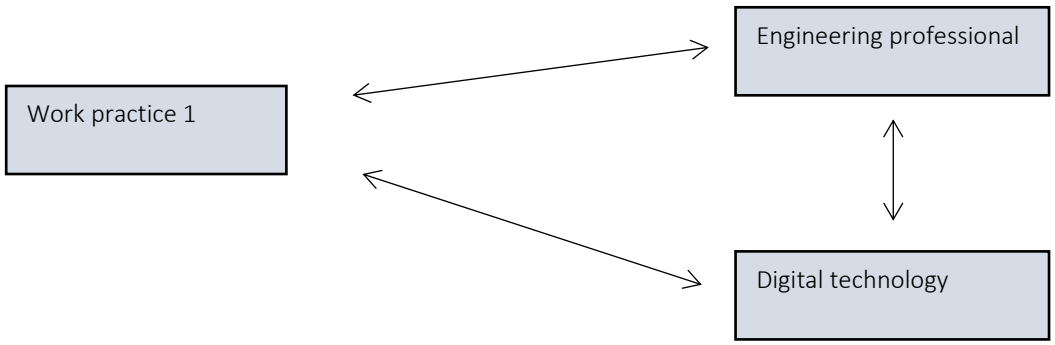
Interview coding examples

INTERVIEW CODING EXAMPLES	
Code	Interview excerpt / quote
Automating work	– We always did it by hand. Now, it is a computerized management system, so we don't remember it (Ep1) – Then we digitalize it by using Excel where you put five and five and you can automatically ask it to calculate what it is (Ep2)
Changing work	– You can push the boundaries and much more with the technology we have now. And the tech was available 10 years ago (EP7) – I have seen changes but not in the software perse or in the technology but more about the capacity of others or myself to automate some tasks. Using the same software (EP3)
Digital impact positive	– well not.....Automated, you still need to use programs and things like that to do the work but instead of sitting down with a pen and a paper and tapping into kind a what's involved you can you can do it a lot easier and you can run things for the whole month or so instead of having papers for the whole month and then filing (Ep5) – Now in theory. You could do all your comments while you are on site and then by the time you get back to the office you will have a report ready to issue (Ep6)
Simulating (Feeds into digital doing/ performative action)	– Physical characteristic is obviously something we simulate in structural. and then. External f*actors* on to the physical properties (EP7) – It is not real but we try to put it in the scenario and we try if it works or not. Like, when we having some machine and if it's really not available in the field but we make it similar. And we try it out if it is working or not. That is the simulation we do in the projects (Ep1)
Digital nature (Feeds into *enactment*)	– [name digital technology] is used predominantly for Modelling and documentation of the services and structure and while I think there are some things we can do in there but we generally do the modelling or simulation outside of [] and push that back into [] (Ep4) – Because digital technology doesn't always give you the output you want or doesn't work exactly as you thought it might. So, you need to understand why it is not doing that. The issue the trouble and how you solve it (Ep2)
Human capabilities for digital	– some of the processes have required re-learning how to do things. And so that software, like the troubleshooting because it's the first time you use some of this technology (EP6) – But in five years you will be redundant if you haven't got the programming skills. Especially in my industry and the main, BIM is already ...if you cannot do BIM, you're already redundant. Then you've got to be at least at a managerial level where you're not part of the routine (Ep7)
Knowing-how	– I think it ties in with the things we're doing are so complex. You got no idea what the right answer is when you start (Ep7) – Both can have. You need to be able to understand that system, analyse the system and be able to provide recommendations to enhance that system or change a task to complete (Ep2)

Although I initially searched for complex statistical techniques to analyse my data and I have learned some of these techniques in IBM-SPSS-25, I came to realise that the adoption of a practice-theory did not advocate for statistical data analysis techniques but analytical data analysis approaches (Nicolini, 2012). Therefore, I decided to use the graphical representation of possible relations in my data as this is believed to "quickly establish the strengths and weaknesses of relationships, including positive and negative attributes, visually" (Wilkinson & Birmingham, 2003, p. 81). For example, the visual depiction of the focus on the concepts of the practice-theory allowed for a depiction of the relational network, such as in *Actor*-Network Theory such as that work tasks, skills, digital technologies, and learning modes could be analysed for possible interconnected relationships and even related sentiments. This was done for the whole *actor*-network of the practice, such as the simple example depicted below which shows the possible symmetrical connections between the practice, professionals and digital technology, and then followed up and preceded with a more extensive and in-depth discussion in words.

Figure 6.

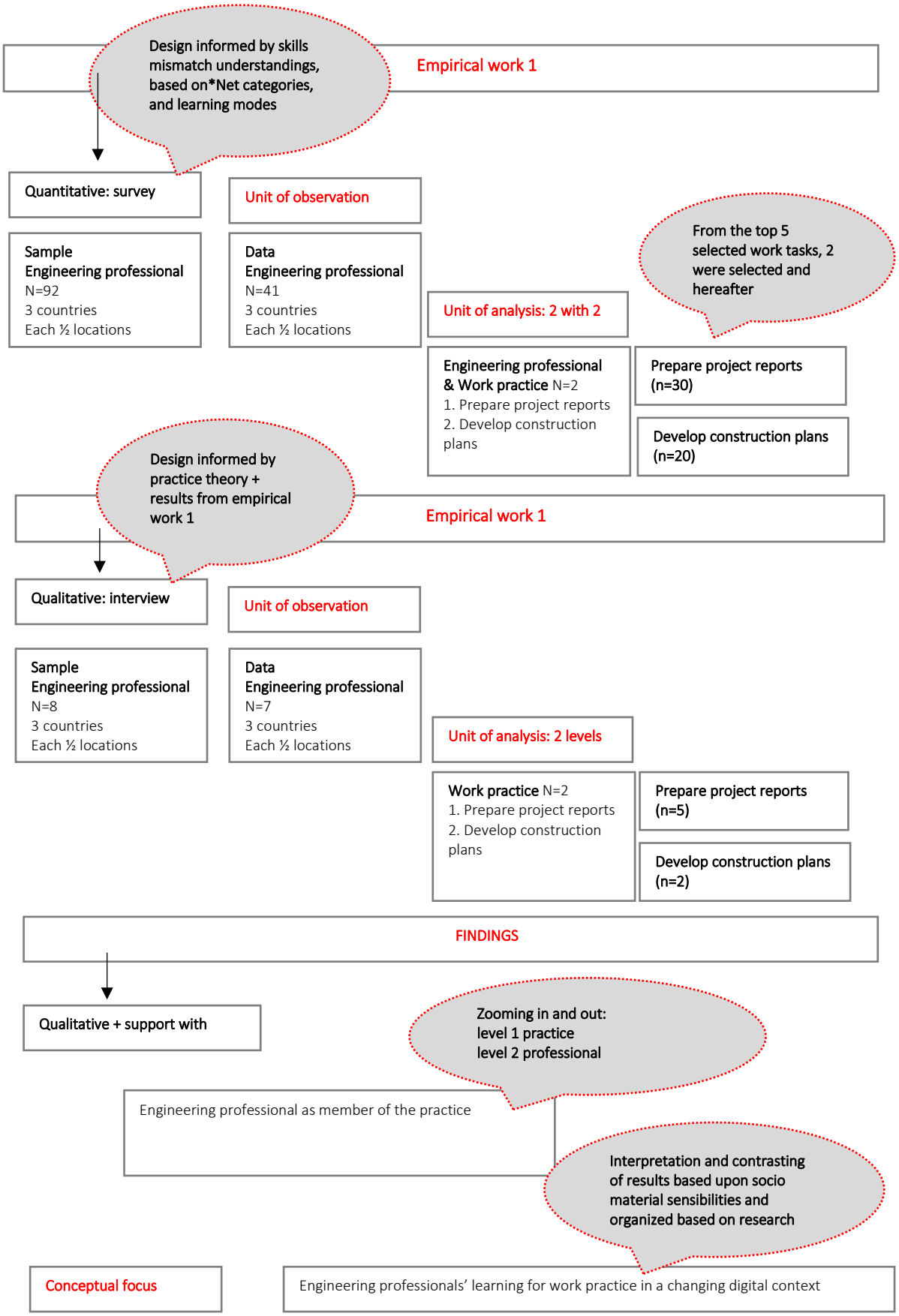
Research constructs – work, digital technology and professional



Since multiple steps were involved in the sequential design and execution of the study and the study's design became complex, the different steps are illustrated in Figure 7below to summarize them and make them clear. The figure shows the two different empirical steps of the survey and interview phase, the distinction between unit of observation (data object) and unit of analysis and their research methods, instruments and sample numbers that were used in this thesis.

Figure 7.

Summary of research methodology



Finally, the sociomaterial sensible concepts that were pulled out for the results were associated with agency, *enactment*, *translation,* and delegation. Agency was useful to understand who was having defining power in the professional sense by *performing* professional work activities or at least impacting them which may be understood as *enactment* upon each other. This was useful to define who and what the relations were. In *enactment*, to be able to *enact* upon, was dependent on successful *translation*s and was useful to understand the requirements of professionals in relation to digital technologies in their work practice. Delegation was found useful to understand when something else was used as intermediary for the defining professional responsibility. They were discussed in Chapter 4 and will be used to describe the insights in Chapter 8.

5.8 Chapter summary

The research methodology that was followed to contribute and answer the research questions in this thesis was discussed. In the mixed-methods sequential case study approach that was selected, I showed that I have used both an individual professional account as well as a practice motivated account by following sociomaterial sensibilities in researching learning for work. This chapter has shown that for the quantitative part a specific research instrument was required since existing instruments were not linking the research areas of concern of digital technology, the human *actor*, and individual skills directly connected to a work-practice. Therefore, I developed a specific research instrument for the survey phase of the research and named the survey: *STWL-Survey - Skills, Technology and Learning for Work Survey*. I showed in this chapter that the survey was completed by 41 engineering professionals working in the construction industry. After the survey, the research continued with voluntary research informants and I conducted semi-structured interviews with 7 of them. I discussed that the empirical work of the research was completed in July 2019. For the analysis part, the two core engineering practice units were identified for further exploration, while at the same time allowing me to focus on the individual professional as a member of the practice of *preparing project reports* and *developing construction plans.*

The results of this study are shown in Chapters 6 and 7 before a discussion of the insights connected to the research questions of this thesis follow in Chapter 8, and the thesis is concluded with modest contributions and recommendations in Chapter 9.

CHAPTER 6 -ONE SIZE DOES NOT FIT ALL– CASE STUDY SURVEY RESULTS

6.1 Introduction

In this chapter, I present the two main survey findings derived from the quantitative work of this thesis that followed the individual skills approach to explore learning for work. The main argument derived from the survey insights is that *one size does not fit all* applies to learning for two highly digitalized core professional engineering work practices. Professional learning should be allowing for different options since variances across professional levels and countries appear in the results of the empirical work, but some stabilised learning mechanisms appeared relevant such as learning from colleagues and learning a foundation in school. Furthermore, the chapter also shows that *one size does not fit all* applies to the finding about relations between professionals and digital technology. The degree and extent of their relation vary across professional levels and thus contextual f*actors* require consideration when researching learning for work.

This chapter shows first that professionals have strong relations with digital technologies in their work practice and variances across professional levels and countries exist. The use of specific digital technologies is varied and no full consistency among respondents about specific digital technology use in work was visible. The implications of digital technology use in work for professionals ranged from replacing to advancing human skills and varied across different professional levels. The digital technology to work implications was also considered as relations. For higher professional levels, such as engineering and managing professionals, the digital technologies were advancing human skills while for technical professionals the case was more likely an issue of replacing of human skills and a form of automation had occurred.

This chapter shows that professional learning of the engineering professionals working in the construction industry happens predominantly through practice with learning mechanisms such as trial and error or learning from colleagues at work. Formal education is also relevant since a big share of the survey respondents selected the learning mechanism related to formal schooling. The chapter illustrates that the engineering professionality of the participating engineering professionals working in the construction industry is multidisciplinary and dimensional because the exploration showed various kinds of skills and knowledge that were found in different dimensions.

The chapter continues to show that not all professionals are mastering working with digital technologies which may interfere with their professional responsibility – the *translation* of the digital

technology into their professional practice since they may not be fully capable of translating the digital technologies meaningful into their practice.

This chapter discusses the empirical results from the survey by using the practitioner as a unit of analysis but organised around the grouping of professionals constituting the particular two selected work practices of *preparing project reports* and *developing construction plans*. The data from the individual professionals in the practice were used to exemplify what is common and what is different among different contextual dimensions and could thus be perceived as zooming in and out between practice and professional. In addition to these lenses, variances among professional levels - technical, engineering, and managing - were used to exemplify variances across professionals and show the importance of contextual f*actors* when researching learning for the specific two core engineering work practices. When discussing the results, the use of %, unless otherwise specified, means the percentage of respondents. The identifiers of practice 1 and 2 respectively are sometimes used to refer to the specific data for the work-practice of *preparing project reports* and the work-practice of *developing construction plans*.

6.2 Summary of the survey insights – one size does *not* fit all

This chapter shows the exploration of the survey results which support the major high-level findings which can be derived into three areas of concern. The first area of concern deals with the relation between the engineering professionals and digital work technologies which will be further illustrated in chapter 6.3 and 6.4. The second area of concern deals with the individual skills and knowledge base required of the engineering professionals to be a member of their engineering work practice which will be further explored in section 6.5. The third and last area of concern relates to the professional learning required to develop the individual skills and knowledge base of the participating engineering professionals which is further illustrated in section 6.6.

In the first area of concern, the area of work and relation with digital work technologies. This chapter illustrates that *one size does not fit all* applies to the survey finding about relations between professionals and digital technology. The degree and extent of their relation vary across professional levels and thus contextual f*actors* require consideration when researching learning for work. Some of the participating engineering professionals working in the construction industry who were derived into professional level and country groups were showing relations with digital work technologies which could be regarded as negative and others were showing relations that could be regarded as positive relationships. Also, the notion of innovation appeared more relevant among higher

engineering levels as opposed to lower engineering levels. The survey results showed the following similarities and differences:

- Variances across different professional levels, countries and work context (practice) exist but similarities are that all engineering professionals are using digital technologies significantly in their core work practices (90%).
- The use of specific forms of digital technologies varies among respondents in groups, across groups and countries. Whereas managing levels and higher engineering levels work with a diversity of sophisticated technologies that can be understood as a process, technical professionals work more with IOT (100%) and mobile devices and apps (83%) which could be understood as digital technologies conceptualised as tools.
- Digital technology has changed the work practice to some extent for almost all professionals since about 90% of them selected that they perceived a partial or complete change. The one outlier can be found among managing professionals in the UAE. Almost all professionals expect further change in the work practice towards 2023.
- Digital technology has advanced the work of most professionals (84%) while only 3% believed that it has resulted in a disruption of their work. The main variance was found among technical professionals in the UAE and engineering professionals in SA in work practice 2.
- Digital technology has enhanced the human skills for higher professional engineering levels in both core work practices as over 90% selected that they perceived a partial or complete enhancement of their work skills in work practice 1 and 100% in work practice 2. The only outliers were engineering professionals in Australia in work practice 1 and technical in South Africa in both work practices.
- Digital technology has *not* significantly changed the need for human skills for all professionals, the selection was either *not* (53%) and *partially* (40%). The major variance was found among technical professionals in the UAE in work practice 1 and managing in the UAE in work practice 2. This impact is understood as negative because it can result in loss of work tasks or responsibilities of the professional.

In the second are of concern, namely that of the individual skills and knowledge base. The main finding is that professional learning may need to have a multi-disciplinary and -dimensional nature where both the real daily engineering work practice and theory component is present. The survey results showed the following similarities and differences:

- For skills, the similarities across professional levels and countries were found in both work practices: reading comprehension (87%), writing (83%), critical thinking (90%), and time management (67%). Whereas for knowledge, similarities were found for administration and management (80%), engineering and technology (77%), and building and construction (77%). For the second work practice,

design (70%) was also similar across the groups. A difference was the coordination skills between SA 36% and the UAE 83%.

- Design knowledge in SA with 79%, The UAE with 17% and AU with 70%. Law and government knowledge were rated more important for SA with 57% across all professional groups, whereas it was in the other countries only 10 and 17 % for the higher engineering levels. These general skills and disciplinary engineering knowledge are strongly correlated (about 70%) which indicates the need for considering them in professional learning.
- The main finding for digital skills and knowledge is that some common combinations of knowledge and skills among all professionals in all levels were found, but differences between professional levels existed, especially differences that can be traced back to the roles the professionals fulfil in their professional level with technical work and professional responsibilities. For example, more engineering disciplinary specific skills and knowledge were key, as opposed to the skills/knowledge selected to do the work practice without referring to the digital. An agreement was reached for the general skills whereas disagreement was found for skills such as programming and systems evaluation for lower engineering levels and for technology design for higher professional levels. For digital knowledge, agreement was found in the disciplinary engineering knowledge, and administration and mechanical knowledge was found more for lower engineering levels.
- The survey also revealed that not all engineering professionals are mastering working with digital technologies which may interfere with the ability to fully *enact* upon the digital technologies as to use them as was intended with the design of the developer so that it can be translated in the core engineering work practice. Namely, about 47% and 42% in both core practices selected that they had not mastered working with digital technologies in their work. However, only technical and engineering professionals in SA and the UAE were more confident in their mastery. Some managing professionals in all countries and more engineering professionals in AU agreed that they had not mastered working with digital technologies.

In the third and last area of concern, namely that concerned with the professional learning require dot be an individual member of the selected core engineering work practices. The main finding is that *one size does not fit all* applies to learning for two highly digitalized professional core engineering work practices. Professional learning should be allowing for different options and learning 'locations' since variances across professional levels and countries do appear in the survey results. Further to that, although the learning in schooling is valued, learning through and from others and in the workplace is perceived as important. The survey results showed the following similarities and differences:

- Learning skills for work happens through both work participation and academic education. Among learning skills, the most selected learning modes were found in the participation corner with mechanisms such as trial and error and using intuition/gut feeling. Variances across countries and professional levels existed but variances within groups also existed.
- Learning knowledge happened mostly through academic schooling (40% and 45%), while learning modes found in the participation corner were significantly less selected than among skills. Considering the association of schooling to learn a formal knowledge base, this result is not surprising. Variances across professional levels and countries exist. For example, formal academic schooling is much less selected among professionals in the UAE with 28% while 47% in SA and 35% in AU selected formal schooling being important for learning knowledge.
- Learning to put digital technologies into practice happens while working (57% for practice 1 and 63% for practice 2). The only real outliers that were identified were technical and managing professionals in SA who opted more for learning in school and other in both work practices.

In sum, the survey results elaborating on the three major areas of concern in the research (work, skills, and learning) were discussed in this section and the main insights which were derived based on these results briefly discussed. In the next four sections, I further elaborate on the high-level insights which were explored in this current section and further support them with data.

6.3 Highly digitalized work practices with use variations

The data from the survey showed that the two selected core engineering work practices are highly digital technology-infused, with a variety of digital technologies among all the professionals, and with variations across professional levels and countries. This result is based on two indications that were shown in the survey. (1) About 90% of respondents in both work practices are using digital technologies significantly in their work, with a mean of 69,2% for practice 1 and 82,7% for practice 2. Responder agreement in the work practice of *preparing project reports* in the three different countries for engineering and managing professionals was reached, but not for technical staff in the UAE. The UAE average of 31% of respondents for digital technology use in work was different from that of South Africa with 85%.,(2) Among all respondents, different types of digital technologies are used in the work practices with *Mobile devices/apps*, *BIM*, *CAD*, *IOT* and *Simulations* being the most frequent. In *preparing project reports* among both samples of technical professionals in the UAE and South Africa, all selected *IOT*, while 83% selected *Mobile devices/apps* being used in the practice, while in the practice of *developing construction plans* it was the other way around, with *Mobile devices/apps* being selected by all technical professionals. While *Big data and analytics* were *not*

selected among engineering and managing staff in Australia, it was, however, selected among the small engineering sample in the UAE, and the managing staff in South Africa.

6.3.1 A high share of digital technology use in the practices.

The survey revealed a high share of digital technology use in both work practices which was gathered by posing the question, *I use digital technology for…% in the work-task.* It is shown in Table 4.

Table 4.

Use of digital technologies used in the work practices

THE INTENSITY OF DIGITAL TECHNOLOGIES USED IN THE TWO SELECTED CORE ENGINEERING WORK PRACTICES

		Total				**Australia**		**South Africa**			**United Arab Emirates**		
Work dimensions		*Total*	*Technical*	*Engineering*	*Managing*	*Engineering*	*Managing*	*Technical*	*Engineering*	*Managing*	*Technical*	*Engineering*	*Managing*
Work practice 1	**Cases**	***30***	***6***	***15***	***9***	***8***	***2***	***3***	***5***	***6***	***3***	***2***	***1***
Digital use (a.)	Above 50% in work	86.7%	66.7%	93.3%	88.9%	87.5%	100.0%	100.0%	100.0%	83.3%	33.3%	100.0%	100.0%
	Mean (%)	69.2%	57.8%	74.8%	67.4%	77.8%	65.5%	84.7%	76.0%	66.0%	31.0%	60.0%	80.0%
Work practice 2	**Cases**	***20***	***5***	***10***	***5***	***5***		***4***	***5***	***4***	***1***		***1***
Digital use (b.)	Above 50% in work	95.0%	100.0%	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%	100.0%		100.0%
	Mean (%)	82.7%	85.0%	80.6%	85.0%	78.8%		89.5%	82.4%	82.7%	67.0%		92.0%

Note:
This table demonstrates with the mean (%), the intensity of digital technology use in the selected engineering work practices. Based on the STWL survey results as a share (%) of total work.
An above 50% of use in the work practice has been regarded as a significant use and the % of respondents is depicted. The table is based on the STWL survey results, generated with IBM SPSS-25 and further amended in MS Excel.
(a) Digital use of work technologies in the work practice of preparing project reports (N=30)
(b) Digital use of work technologies in the work practice of developing construction plans (N=20)
Source data: 2018-2019 STWL-survey (de Munnik, 2020)

What appears is a high percentage for digital technology use. This supports the argument that the engineering work practices are highly digitalized. Namely, if the perceived percentage of use is about 70%, digital technology is used in a big part of the daily work practice of these engineering professionals. None of the other core engineering work practices defined with the survey data received a lower than 60% use in work which may indicate that for a significant part of the complete core engineering work, the professionals in the core engineering work practice use digital technologies. To what extent and with which kind of variation and impact they use digital technologies, was not answered through the survey but was part of the interviews. This is discussed in the next chapter when discussing the qualitative results.

The survey results were consistent among the different respondents as found by looking at the distance between the mean and median. For example, in the work practice of *preparing project reports*, the distance between the mean (69) and median (74) of this part of the survey data were not that high, which may indicate that there is minimum variance in responses among the participants in this work practice and this small variance could indicate that there is respondent agreement. For the work practice of *developing construction plans*, the distance between mean (83) and median (82) was even less. Although respondent agreement between engineering and management professionals was visible in both work practices, this was not the case for the small, but equal share of technical staff in the work practice of *preparing project reports*. While all the South African technical professionals were depicting a high use in work with a mean of 85%, the technical professionals in the UAE did not reach an agreement and showed a mean of 31%. This is surprising because one would assume a higher share of digital technology use in a more advanced and innovative country. There was only one extreme outlier from the UAE-technical group who challenged the range of percentage selections extremely and remarkably. This was one of the candidates that participated during the interview whose results will be discussed in the next chapter. For the work practice of developing plans, there was only one technical professional from the sample in the UAE but with 67% compared to the averages of other groups and in other countries this was also slightly different.

6.3.2 Different digital technologies and variances across respondents.

This second section focuses on the digital technologies used in the work practices. The insights are based on the survey results explicitly related to each of the specific core engineering work practices. Table 5 shows the digital technologies that professionals used in the two core engineering practices. In the table, the percentages in the second column show the digital technologies selected in the work practice. *Mobile devices/apps* are the most popular, since more than 50% of the professionals selected this digital technology. This result is not surprising since this technology is easily recognizable considering that owning a mobile device is common nowadays. The table also shows that only one selection – *Mobile devices/apps* – received an above-50% selection in work practice 1 and two selections, *mobile devices/apps* and *BIM* in work practice 2. This implies that the latter work practice is more digitalized that the former. The variation of digital technology selections in both work practices indicates that there is no real consistency in digital technology use among respondents. This makes these work practices highly digital technology-infused, with a high variety of the type of digital technologies but with a minimal responder agreement. This low responder agreement is shown by the minimal share of digital technologies that received selections by at least 50% of the respondents. Then, BIM, IOT, CAD and simulation also received significant selections among respondents whereas

drones, GPS trackers, laser scanning, 3D printers and robotic constructors did not receive so much attention. The total share (SUM%) is used for comparing the degree of digital technology use in both practices. They appeared similar, although the practice of *developing construction plans* is slightly

Table 5.

Specific digital technologies in the two work practices

THE DIGITAL TECHNOLOGIES USED IN THE TWO SELECTED CORE ENGINEERING WORK PRACTICES

		Total	
Digital technology in work		Work practice 1	Work practice 2
Digital technologies (a.)	Mobile devices and apps	53.3%	60.0%
	BIM	36.7%	50.0%
	Simulation	20.0%	35.0%
	Scanning	3.3%	10.0%
	Drones	0.0%	0.0%
	GPS	6.7%	0.0%
	3-D	3.3%	0.0%
	Robotics	0.0%	0.0%
	VRAR	3.3%	10.0%
	Big Data and Analytics	10.0%	5.0%
	IOT	26.7%	25.0%
	Sensors	0.0%	5.0%
	Unmanned Vehicles	0.0%	0.0%
	CAD	30.0%	50.0%
	MAP	3.3%	10.0%
	Other	33.3%	20.0%
	total selections	*230.0%*	*280.0%*
	cases	*30*	*20*

Note:

This table demonstrates the selections of the specific digital technologies used in the engineering core work practices
The percentages (%) which are indicated are the share of survey respondents that selected the digital technology in the work practice

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

(a.) Digital work technologies in both work practices 1 and 2

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

more digitally infused. This also applies to the selections of specific digital technologies which are similar in both work practices and may support an argument to focus on these digital technologies in the research as being relevant to a high share of core engineering work.

Among the selections in the *other* category seen in the table, it was surprising that specific brand names of programs and technologies were mentioned instead of additional categories. Either, the respondent did not know how to divide the digital technology, or their digital technology use consisted of more than one survey category. However, in that latter case, they could have selected both categories. For example, in the work practice of *preparing project reports*, most of the other selections that professionals made were Microsoft Office (6x) and a few more were found in Simulation and BIM (2x). While the MS Office software package is perhaps difficult to categorize in

any of the given listings - and recent possibilities do allow them to be used in more advanced and sophisticated applications found in Simulations and BIM, - the division of the latter two selections of *other* could have been divided into the BIM and Simulation categories. However, this was not done in the research. The survey used the loop and merge design which explicitly related outcomes of digital technologies, change, skills, knowledge and learning for work practice. This explicit relating was done by building forward on previous selections. Therefore, an amendment of earlier question results was *not* possible and amending data at this stage would have changed the reliability of any further survey analysis. Variances among professional levels and countries did emerge from the survey results as is illustrated with Table 6.

Table 6.

Digital technologies used in the core engineering work practices

THE DIGITAL TECHNOLOGIES USED IN THE TWO SELECTED CORE ENGINEERING WORK PRACTICES

		Total				**Australia**		**South Africa**				**United Arab Emirates**				
Digital technology in work dimensions		*Total*	*Technical*	*Engineering*	*Managing*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*
Work practice 1	Mobile devices and apps	53.3%	83.3%	40.0%	55.6%	37.5%	50.0%	40.0%	100.0%	60.0%	50.0%	64.3%	66.7%	0.0%	100.0%	50.0%
	BIM	36.7%	16.7%	33.3%	55.6%	12.5%	50.0%	20.0%	33.3%	60.0%	50.0%	50.0%	0.0%	50.0%	100.0%	33.3%
Digital technologies (a.)	Simulation	20.0%	33.3%	20.0%	11.1%	12.5%	0.0%	10.0%	0.0%	40.0%	16.7%	21.4%	33.3%	0.0%	0.0%	16.7%
	Scanning	3.3%	16.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	33.3%	0.0%	0.0%	16.7%
	Drones	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	GPS	6.7%	16.7%	0.0%	11.1%	0.0%	0.0%	0.0%	0.0%	0.0%	16.7%	7.1%	33.3%	0.0%	0.0%	16.7%
	3-D	3.3%	0.0%	0.0%	11.1%	0.0%	0.0%	0.0%	0.0%	0.0%	16.7%	7.1%	0.0%	0.0%	0.0%	0.0%
	Robotics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	VRAR	3.3%	0.0%	6.7%	0.0%	0.0%	0.0%	0.0%	0.0%	20.0%	16.7%	0.0%	0.0%	0.0%	0.0%	0.0%
	Big Data and Analytics	10.0%	0.0%	6.7%	11.1%	0.0%	0.0%	0.0%	0.0%	0.0%	16.7%	7.1%	0.0%	50.0%	0.0%	16.7%
	IOT	26.7%	100.0%	6.7%	11.1%	12.5%	0.0%	10.0%	100.0%	20.0%	0.0%	28.6%	100.0%	0.0%	0.0%	50.0%
	Sensors	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Unmanned Vehicles	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	CAD	30.0%	33.3%	33.3%	22.2%	12.5%	50.0%	20.0%	0.0%	60.0%	16.7%	28.6%	33.3%	50.0%	0.0%	33.3%
	MAP	3.3%	0.0%	6.7%	0.0%	0.0%	0.0%	0.0%	0.0%	20.0%	0.0%	7.1%	0.0%	0.0%	0.0%	0.0%
	Other	33.3%	16.7%	46.7%	22.2%	75.0%	0.0%	60.0%	0.0%	20.0%	33.3%	21.4%	33.3%	0.0%	0.0%	16.7%
	total selections	230.0%	316.7%	200.0%	211.1%	162.5%	150.0%	160.0%	233.3%	300.0%	233.3%	242.9%	333.3%	150.0%	200.0%	250.0%
	cases	*30*	*6*	*15*	*9*	*8*	*2*	*10*	*3*	*5*	*6*	*14*	*3*	*2*	*1*	*6*
Work practice 2	Mobile devices and apps	60.0%	100.0%	40.0%	60.0%	20.0%		20.0%	100.0%	60.0%	50.0%	69.2%	100.0%		100.0%	100.0%
	BIM	50.0%	40.0%	60.0%	40.0%	60.0%		60.0%	50.0%	60.0%	50.0%	53.8%	0.0%		0.0%	0.0%
Digital technologies (b.)	Simulation	35.0%	20.0%	40.0%	40.0%	40.0%		0.0%	25.0%	40.0%	25.0%	30.8%	0.0%		100.0%	50.0%
	Scanning	10.0%	0.0%	10.0%	20.0%	20.0%		20.0%	0.0%	0.0%	0.0%	0.0%	0.0%		100.0%	50.0%
	Drones	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%
	GPS	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%
	3-D	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%
	Robotics	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%
	VRAR	10.0%	20.0%	10.0%	0.0%	0.0%		0.0%	0.0%	20.0%	0.0%	7.7%	100.0%		0.0%	50.0%
	Big Data and Analytics	5.0%	0.0%	0.0%	20.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		100.0%	50.0%
	IOT	25.0%	80.0%	0.0%	20.0%	0.0%		0.0%	75.0%	0.0%	0.0%	23.1%	100.0%		100.0%	100.0%
	Sensors	5.0%	0.0%	0.0%	20.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		100.0%	50.0%
	Unmanned Vehicles	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%
	CAD	50.0%	40.0%	70.0%	20.0%	60.0%		60.0%	50.0%	80.0%	25.0%	53.8%	0.0%		0.0%	0.0%
	MAP	10.0%	0.0%	20.0%	0.0%	0.0%		0.0%	0.0%	40.0%	0.0%	15.4%	0.0%		0.0%	0.0%
	Other	20.0%	20.0%	20.0%	20.0%	20.0%		20.0%	25.0%	20.0%	25.0%	23.1%	0.0%		0.0%	0.0%
	total selections	*280.0%*	*320.0%*	*270.0%*	*260.0%*	*220.0%*		*180.0%*	*325.0%*	*320.0%*	*175.0%*	*276.9%*	*300.0%*		*600.0%*	*450.0%*
	cases	*20*	*5*	*10*	*5*	***5***		***5***	***4***	***5***	***4***	***13***	***1***		***1***	***2***

Note:

This table demonstrates the selections of the specific digital technologies used in the selected engineering core work practices based on the survey results

The percentages (%) which are indicated are the share of survey respondents that selected the digital technology in the work practice

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

(a.) Digital work technologies in both work practices 1 and 2

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The table shows that variances among professional levels and countries existed. For example, technical professionals in South Africa seem to work with BIM while none of the technical professionals in the UAE selected BIM. For simulation, none of the managing professionals in Australia selected working with simulations while all the managing professionals in the UAE did and 50% of those in South Africa. Working with CAD was more preferred among managing professionals in Australia and to a lesser extend among managing professionals in South Africa and not in the UAE. The rows with total selections in the upper and lower part of the table show that variances between work practices are also relevant. The work practice of *developing construction plans* shows higher total percentages of digital technology selections which may indicate that this work practice is more digitalised than opposed to the work practice of *preparing project reports*.

For the reason that the variances among respondents are at stake in this thesis, the following discussion sheds light on the contextual differences and similarities among the respondents that selected the digital work technologies, which is depicted in Table 7. However, the brief discussion given here is limited only to a selection of the survey results, as they will exemplify more about possible contextual differences. For example, the attributes from the professionals that selected BIM in the work practice of *preparing project reports* are from different country contexts. Regarding the engineering discipline, the results were spread but more were found in electrical engineering and none were found in mechanical engineering. Further, more management professionals and only one technical professional were found which may indicate that management is working more with BIM in this practice or perhaps the technical staff are not fully aware that they are working with it.

Table 7.

Details about the selection of BIM

SELECTIONS IN THE WORK PRACTICE PREPARING PROJECT REPORTS

	Engineering professional	Gender (F/M)	Age category (Yrs)	Country context	Education	Workexperience	Professional group	Engineering discipline	worktraining (days)
Selection of BIM	**EP7**	Male	25-34	Well developed	Postgraduate	5-10yrs	Engineer	Structural	12
(a.)	**EPS02**	Male	35-44	Medium developed	Graduate	10+yrs	Engineer	Civil	15
	EPS03	Male	35-44	Well developed	Graduate	10+yrs	Management		5
	EPS04	Male	45-54	Medium developed	Graduate	3-5yrs	Engineer	Electrical	5
	EPS06	Male	25-34	Medium developed	Postgraduate	5-10yrs	Engineer	Electrical	10
	EPS07	Female	25-34	Medium developed	College4	5-10yrs	Technical		
	EPS08	Male	35-44	Medium developed	Graduate	10+yrs	Engineer	Electrical	3
	EPS15	Male	25-34	Well developed	Graduate	10+yrs	Engineer	Structural	
	EPS17	Male	35-44	Medium developed	Graduate	10+yrs	Management		10
	EPS19	Male	25-34	Well developed	Graduate	5-10yrs	Management		5
	EPS20	Female	35-44	Medium developed	Postgraduate	10+yrs	Management		480
Selection of Simulation	**EP1**	Male	25-34	Medium developed	Graduate	10+yrs	Engineer	Assistant engineer	3
(b.)	**EPS04**	Male	45-54	Medium developed	Graduate	3-5yrs	Engineer	Electrical Engineer	5
	EPS06	Male	25-34	Medium developed	Postgraduate	5-10yrs	Engineer	Electrical Engineer	10
	EPS07	Female	25-34	Medium developed	College4	5-10yrs	Technical	Associate - fire technician	
	EPS08	Male	35-44	Medium developed	Graduate	10+yrs	Engineer	Technical Director Electri	3
	EPS15	Male	25-34	Well developed	Graduate	10+yrs	Engineer	Structural Engineer	

Note: This table demonstrates the selections of the specific professionals for the use of BIM and Simulation in the work practice of preparing project reports. The first column shows the designation of the engineering professional. EP means that the respective professional also took part in the interviewing part. The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel.

(a). The selections for BIM (N=30/ N=11) - (b.) the selections for Simulation (N=30/ n=6)

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The main survey finding that can be derived from the survey results that preceded is that the selected core engineering work practices are highly digitalized but the use of specific digital technologies varies across professional levels and countries and among the two work practices. This implies that the context in which the work takes place is relevant and must be considered when discussing anything related to learning for professional practice. It also illustrates that there is a valid point for the current thesis to the notion of digital technologies in work. The next section will therefore address the strength of the possible associations between professionals - work and professional skills.

6.4 Digital technology shows strong associations with professionals

The survey highlighted that digital technology has changed the work practice, and at the same time enhanced human work skills. Nonetheless, digital technology has not significantly changed the need for human skills for higher professional engineering levels in the two engineering work practices. This is the case for four reasons.

(1) About 40% and 60%, and 50% and 40% of the respondents on average indicated that the practices have changed *completely* and *partially* between 2013-2018 in work practices 1 and 2 respectively. Only the small sample of management professionals in Australia perceived less change with 50% and 50% respectively for *completely* and *not*.

(2) Also, about 47% and 47% of the respondents *completely* and *partially* believed that digital technology-enhanced human skills in the work practice of *preparing project reports* whereas 65% and 30% *completely* and *partially* believed this for the work practice of *developing construction plans*.

(3) Also, about 53% of all the respondents did *not* believe that digital technology had changed the need for human skills in the work practice of *preparing project reports* whereas 40% for the work practice of *developing construction plans* shared this view. Only technical staff in the first practice did not align with the average of all professionals, with 50% of them selecting *partially* and 33% *completely*. This can be related to the responses of the technical professionals working in South Africa and the UAE.

(4) In another question in the survey where skills were explicitly referred to as *advanced* and *disrupted* human skills, about 80% of the respondents opted for the *advanced* answer option in both work practices. However, about 10% of the engineering professionals in South Africa for both work practices believed that digital technology disrupted their work and 10% of technical staff in the UAE

for the work practice of *preparing project reports*, while other locations and groups showed no selections for the *disrupted my work* answer. The four points above may further support the earlier point on enhancing human skills rather than replacing them, but more likely for higher professional levels. At the same time, the percentages above show that about half of the professionals perceive some form of replacing occurring, in particular the technical professionals.

The results derived from the survey data were obtained by asking respondents four questions that were associated with the impact of digital technology on work, now and in the future.

- *I believe that digital technology has changed the work task between 2013 and 2018.*
- *I expect that digital technologies will change the work task between 2018-2023.*
- *I believe that digital technologies replaced the need for human skills in the work task.*
- *I believe that digital technologies enhanced human skills in the work task.*

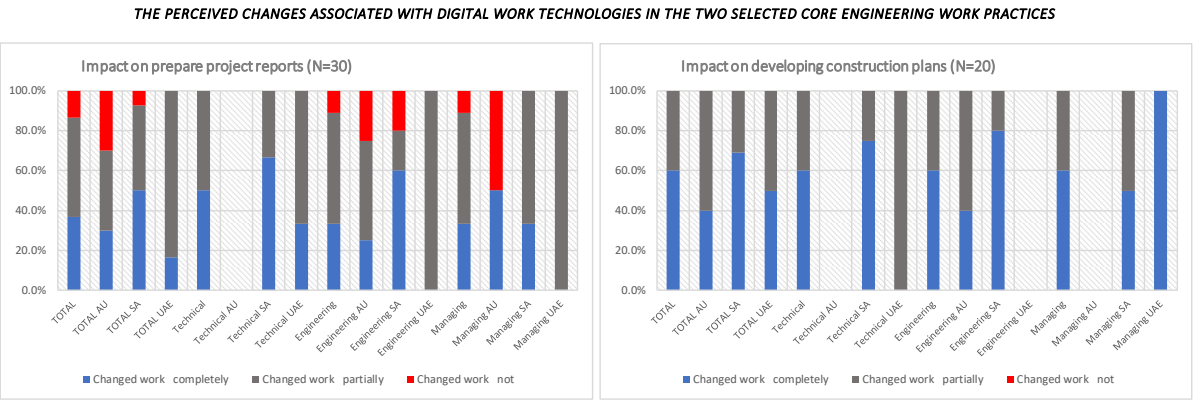
  The variances among the countries and professional groups were analysed through correspondence analysis completed in IBM SPSS-25.

6.4.1 The practice has changed and will further change.

Figure 8 support the first reason the argument in this thesis is made about that the work practices are showing strong relations between professionals and digital technologies.

Figure 8.

Change of work in the two work practices



Note:

These two tables show the perceived change of the two selected engineering core work practices based on the survey results

The percentages (%) are the share of survey respondents that selected the answer option in the respective survey question

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

(a.) The table on the left shows the perceived changes in the work practice of preparing project reports (N=30)

(b.) The table on the right shows the perceived changes of the work practice of developing construction plans (N=20)

(c.) The survey answer options were: Completely (blue), Partially (grey), and Not (red) to the question of: I believe that digital technology has changed the work task between 2013 and 2018

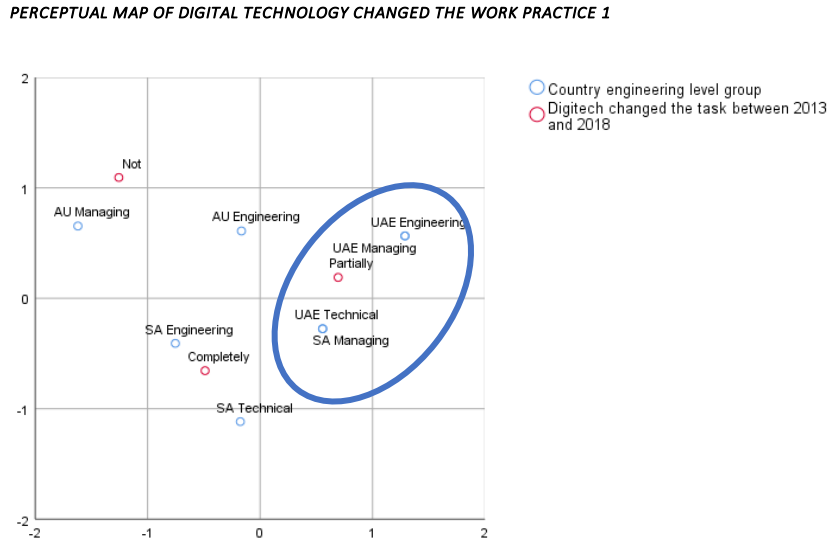
Source data: 2018-2019 STWL-survey (de Munnik, 2020)

What can be derived from the figure is that the high share of blue and grey indicates that most professionals believe that digital technologies have changed their work practice, either *completely* (blue) or *partially* (grey). The only real outliers are the managing professionals in Australia in the work practice of *preparing project reports* and about 50% of them selected the option that the practice has *not* changed. This might be explained as follows: the changes already happened before the timeframe of 2013-2018, the work itself has not changed, a current slowdown of changes, or a lack of management insight into changes for professionals with more engineering and technical responsibilities. Although these explanations could be all relevant, the survey data did not reveal any of these explanations. The correspondence analysis and symmetrical normalization depicted in Figure 9 for the work practice of *preparing project reports* also confirmed some contextual differences among the engineering professionals working in the construction industry who took part in the

survey. What can be seen in Figure 10 is that Australian management showed a strong positive association with the selections for *has not changed the work practice*, while for example, the UAE engineering and managing group showed stronger associations with *has partially changed the work practice*. The visualisation of the correspondence analysis done for the question on further expected change depicted in Figure 10 shows that it is expected that the work practices will change further in the future which indicates the need for this research focus for the future.

Figure 9.

Correspondence analysis of a changing work practice



Note:

This perceptual map is based on a crosstabulation and correspondence analysis with symmetrical normalization

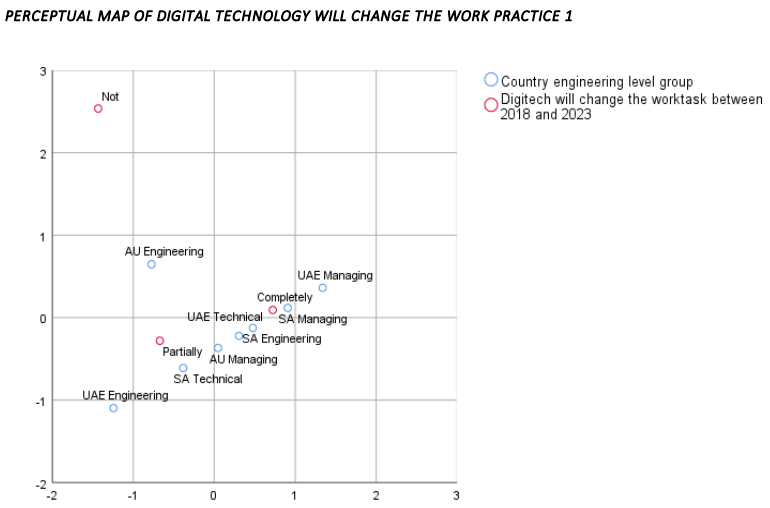
The map demonstrates the perceived change in the work practice of preparing project reports based on the survey results

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
(a.) the proximity of the red and blue circles show which questions options are closely associated with country and engineering level
(b.) the survey answer options were: Completely, Partially, and Not to the question of: I believe that digital technology has changed the work task between 2013 and 2018

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

Figure 10.

Correspondence analysis of expected future changing work practice



Note:

This perceptual map is based on a crosstabulation and correspondence analysis with symmetrical normalization
The map demonstrates the expected future change in the work practice of preparing project reports based on the survey results

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
(a.) the proximity of the red and blue circles show which questions options are closely associated with country and engineering level
(b.) the survey answer options were: Completely, Partially, and Not to the question of: I expect that digital technologies will change the work task between 2018-2023

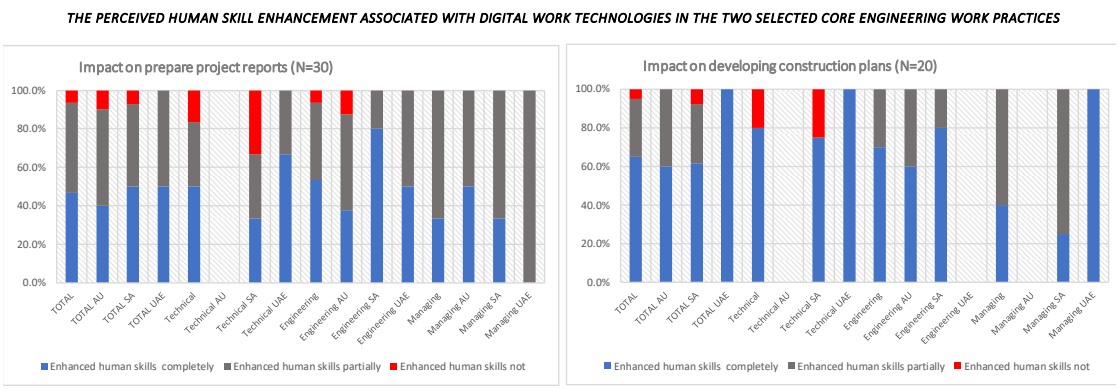
Source data: 2018-2019 STWL-survey (de Munnik, 2020)

6.4.2 Enhanced human skills in the work practices.

The survey revealed that digital technology has enhanced human skills, which can be seen in Figure 11. This enhancement of human skills is understood as a positive relation between digital technology and professionals since human skills are improved or developed. What Figure 11 illustrates is based on the high share of blue (*completely*) and grey (*partially*). It shows that almost all respondents believed, to some degree, that digital technology enhanced human skills in the work task. The only real outliers identified were the technical professionals in South Africa.

Figure 11.

Digital work technology enhanced human skills



Note:
These two tables demonstrate the perceived enhancement of human skills of the two selected engineering core work practices based on the survey results

The percentages (%) are the share of survey respondents that selected the answer option in the respective survey question

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

(a.) The table on the left shows the perceived skill enhancement in the work practice of preparing project reports (N=30)

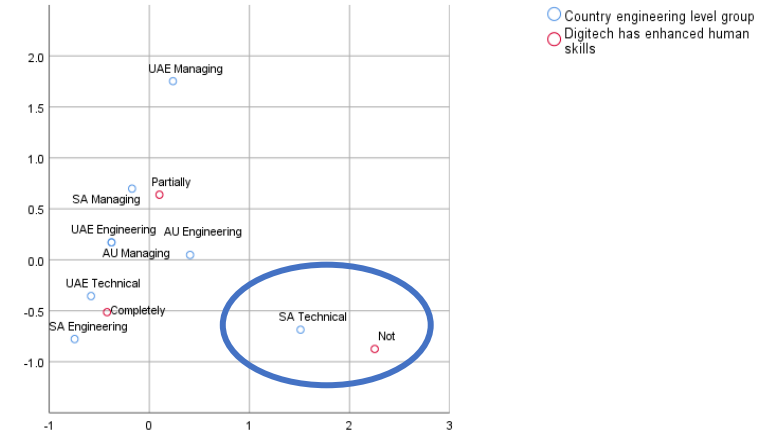
(b.) The table on the right shows the perceived skill enhancement of the work practice of developing construction plans (N=20)
(c.) The survey answer options were: Completely (blue), Partially (grey), and Not (red) to the question of: I believe that digital technologies enhanced human skills in the work task

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

A look into the correspondence visualisation in Figure 12 for the work practice of *preparing project reports* shows indeed close proximity between technical professionals in South Africa and the selection for has *not* enhanced human skills in the work practice of *preparing project reports.*

Figure 12.

Perceptual map enhanced human skills



Note:

This perceptual map is based on a crosstabulation and correspondence analysis with symmetrical normalization
The map demonstrates the perceived enhancement of human skills in the work practice of preparing project reports based on the survey results

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
(a.) the proximity of the red and blue circles show which questions options are closely associated with country and engineering level
(b.) the survey answer options were: Completely, Partially, and Not to the question of: I believe that digital technologies enhanced human skills in the work task

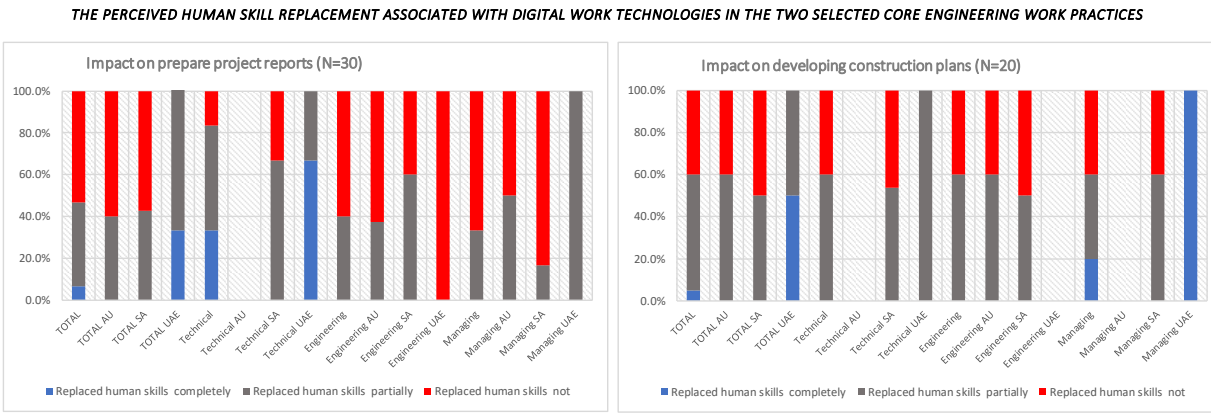
Source data: 2018-2019 STWL-survey (de Munnik, 2020)

6.4.3 Digital technology has not replaced human skills.

The survey revealed that for the participating engineering professionals digital technology has *not* significantly changed the need for human skills because the survey question was referring explicitly to the perceived replacement of human skills. This replacement is understood as a negative implication for the individual engineering professional since it can result in a loss of work tasks or responsibilities for the professional. The synthesized survey results are depicted in Figure 13.

Figure 13.

Impact of digital technologies on human skills - Replaced human skills



Note:

These two tables demonstrate the perceived replacement of human skills of the two selected engineering core work practices based on the survey results

The percentages (%) are the share of survey respondents that selected the answer option in the respective survey question

The tables are based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

(a.) The table on the left shows the perceived skill replacement in the work practice of preparing project reports (N=30)

(b.) The table on the right shows the perceived skill replacement of the work practice of developing construction plans (N=20)

(c.) The survey answer options were: Completely (blue), Partially (grey), and Not (red) to the question of: I believe that digital technologies replaced the need for human skills in the work task

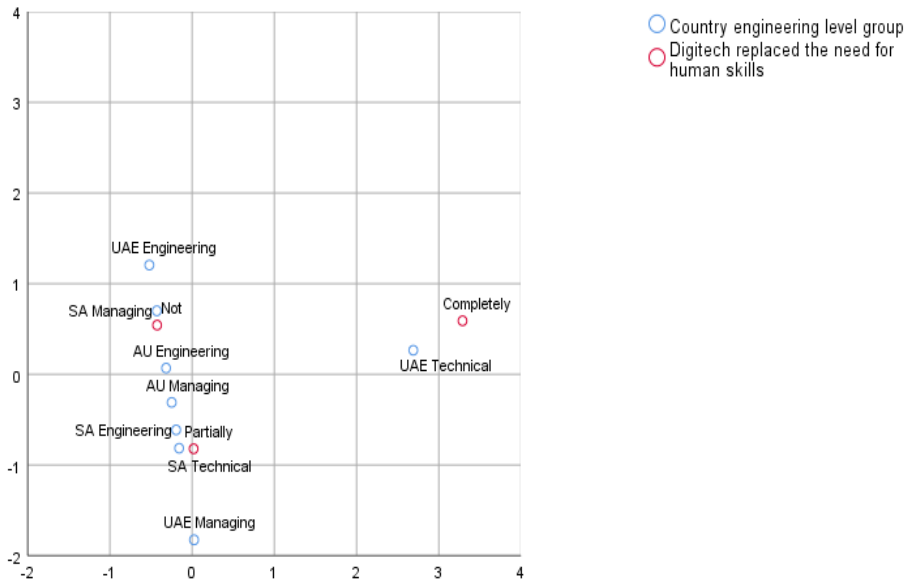
Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The survey results shown in the figure combined with the correspondence analysis shown in Figure 14 reveal that most engineering professionals had *not* experienced a replacement of human skills. This is understood as a positive relationship because it is less likely that they believed that digital technology has replaced the need for human skills. However, in the work practice of *preparing project reports*, technical professionals in the UAE were identified as an outlier and were more likely to perceive this negative association while in the work practice of *developing construction plans*. This was the case for managing professionals in the UAE.

Figure 14.

Correspondence analysis of- replaced human skills

PERCEPTUAL MAP OF DIGITAL TECHNOLOGY HAS REPLACED THE NEED FOR HUMAN SKILLS IN THE WORK PRACTICE 1



Note:

This perceptual map is based on a crosstabulation and correspondence analysis with symmetrical normalization
The map demonstrates the perceived replacement of human skills in the work practice of preparing project reports based on the survey results

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
(a.) the proximity of the red and blue circles show which questions options are closely associated with country and engineering level
(b.) the survey answer options were: Completely, Partially, and Not to the question of: I believe that digital technologies replaced the need for human skills in the work task

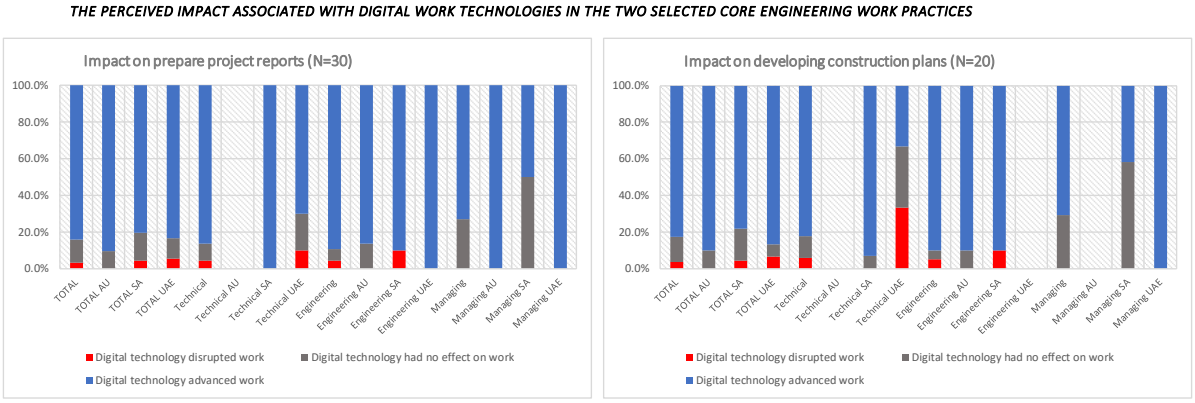
Source data: 2018-2019 STWL-survey (de Munnik, 2020)

6.4.4 Digital technology has advanced the work practices.

The survey revealed that most engineering professionals believed that digital technology had advanced rather than disrupted their daily work practice. This perceived advancement is illustrated in in Figure 15.

Figure 15.

Impact of digital technologies on work - Advanced work



Note:
These two tables demonstrate the perceived impact on the two selected engineering core work practices based on the survey results
The percentages (%) are the share of survey respondents that selected the answer option in the respective survey question
The tables are based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
(a.) The table on the left shows the perceived impact on the work practice of preparing project reports (N=30)
(b.) The table on the right shows the perceived impact on the work practice of developing construction plans (N=20)
(c.) The survey answer options were advanced (blue), no effect on (grey), and disrupted (red) to the question of: This technology has … my work
Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The depiction above shows that most engineering professionals have positive relations with digital technologies at work. Namely, 80% of the respondents selected the *advanced* option in the survey. The only professionals that selected *disrupted my work* were UAE technical and SA engineering professionals in both of the core engineering work practices. The main insight that can be derived from the depiction of survey results in this section is that although digital technologies changed the work practices of most of the participating engineering professionals, these changes were rather having a positive impact on individual skill requirements and little replacement of human skills happened. This tentative finding would support an understanding of innovation where it is understood that:

> technology is of a disruptive nature and displaces the traditional way of working to deliver in a new way (Susskind & Susskind, 2017)

The survey results that were identified to possibly support this argument of innovation were the following:

- The question of a replacement of human skills should have been received *partially* or *completely* as a response.
- The question of whether or not they believed that digital technology has changed the work practice between 2013-2018 should have been received *partially* or *completely* as a response because this could indicate a change of the way of working which is often associated with the notion of innovation.
- The question about the enhancement of human skills should have been received *partially* or *completely* as a response.

Taking the example of the work practice 1 of *preparing project reports*, which are depicted in Table 8, we can understand the following. In the table, it appears as if the work practice of *preparing project reports* is believed to have been impacted by digital technology more on the innovation side of change because it shows a 37% *complete* agreement that digital technology changed the work practice (2013-2018), which is one of the innovation indicators. It also received a 53% percentage for the selection of *Not* in the digital technology replaced human skills question. This could indicate that the work practice is less likely to be automated and perhaps more likely innovated. A high percentage for the selection of *completely* (47%) and *partially* (47%) of the enhancement of human skills further.

Table 8.

Digital technology impact factors in the work practices

DIGITAL TECHNOLOGIES IMPACT ON THE CORE ENGINEERING WORK PRACTICES (% OF N)

	Digital technology							
	will change work practice	**%**	**enhanced human skills in work practice**	**%**	**replaced human skills in work practice**	**%**	**changed work practice**	**%**
Work practice 1	NOT	3%	NOT	7%	**NOT**	**53%**	NOT	13%
	PARTIALLY	47%	PARTIALLY	47%	PARTIALLY	40%	PARTIALLY	50%
	COMPLETELY	50%	**COMPLETELY**	47%	COMPLETELY	17%	**COMPLETELY**	37%

Note:

These two tables show the perceived change of the two selected engineering core work practices based on the survey results The percentages (%) are the share of survey respondents that selected the answer option in the respective survey question based on the N of the work practice

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

(a.) The upper part of the table shows the perceived changes in the work practice of preparing project reports (N=30)

(b.) The lower part of the table shows the perceived changes of the work practice of developing construction plans (N=20)

(c.) The innovation indicating constructs are indicated in bold

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

None of the core engineering work practices *completely* satisfied all of the innovation indicators. However then, by just focusing on the change indicator and on the enhance human skills indicator, I believed that the work practice of *developing constructing plans* was likely to be innovated. This because the work practice received 60%, 60% and 65% for the previous discussed innovation indicators which are shown in the table, The core engineering work-practice of *developing construction plans* is therefore more strongly associated with an innovated practice then the work practice of *preparing project reports*. Both core engineering work-practices stay relevant for the exploration in this thesis since the use of digital technologies, conceptualised as share and the *partially /completely* perceived change of the work practice, make them relevant as focus for the digital technology work context.

The main insight that can be derived from this section is that the relations between the engineering professionals and digital work technologies are strongly bound since both work practices and most of the engineering professionals showed strong associations. However, section 6.3 and 6.4 have shown so far that variances were at stake since not all engineering levels were showing similar results in their use of specific digital technologies and also not all countries showed similar results. In particular the difference between technical and other professional engineering levels and between South Africa, The UAE and Australia are appearing relevant. The focus on innovation is important to consider since the literature in Chapter 2 showed that innovation was associated with implications for professional learning since changing skill needs and implications for lower-level workers arises. However, little was known about the specific skills, knowledge and associated learning in specific engineering work practices and therefore, the next section will deal with the discussion of survey results concerning the individual professional skills and knowledge base.

6.5 The professional knowledge base is multi-dimensional and multi-disciplinary

Professional learning may need to have a multi-disciplinary nature because it appears from the survey that the individual engineering knowledge is multi-disciplinary in both practices. The knowledge is found in all disciplines, namely (1) social science knowledge was found such as *administration and management* (80% and 65%) and *law and government* (33% and 35%); (2) science knowledge such as *building and construction* (77% and 75%), and *computers and electronics* (47% and 50%); design knowledge such as *critical thinking* (90% and 70%), and *active learning* (47% and 40%), and lastly skills found in craft knowledge such as *reading comprehension* (87% and 95%) and *writing* (83% and 75%). The questions in the survey that defined the knowledge and skills were gathered by asking the professionals what skills and knowledge they required to ‘perform’ the specific work practice (task).

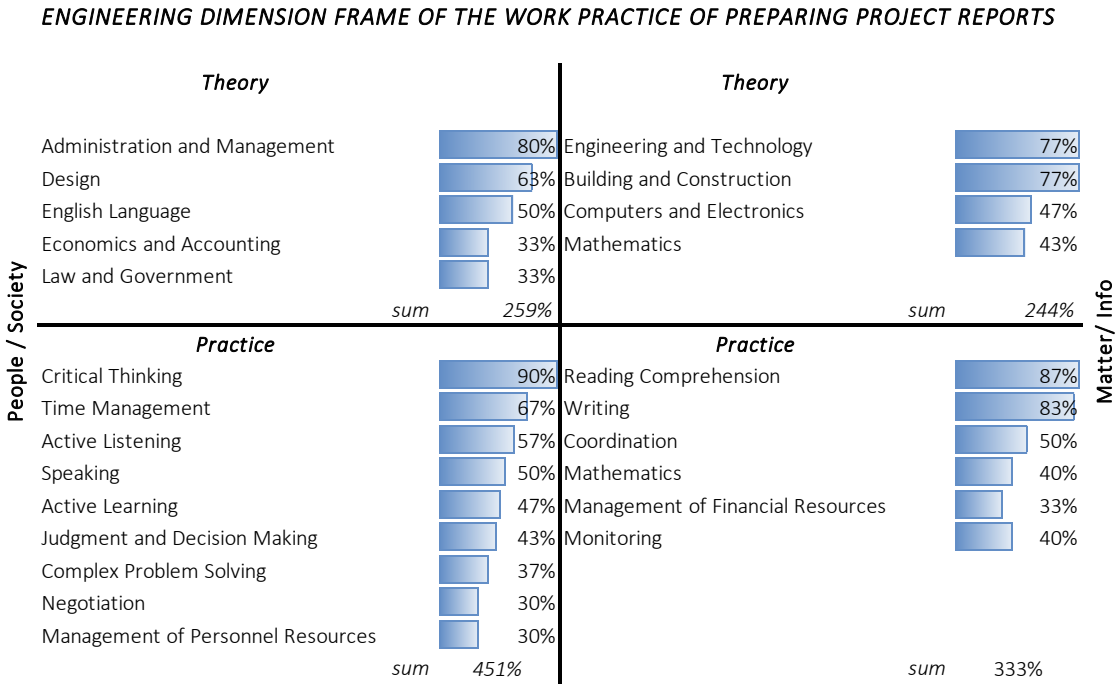
The use of the 'I need…' language was used because the aim was not to measure a mismatch between what they could do and what the job required of them, but rather to make clear the skills required to be a member of that work practice.

6.5.1 Engineering work practices are multi-dimensional and multi-disciplinary.

The survey revealed that the practices of the engineering professionals are multidimensional with both theory and practice found in matter and people. This is according to the multi-dimensional engineering framework of Figueiredo (2014) which was found in the exploration in Chapter 3.

Figure 16.

Engineering dimension frame for preparing project reports



Note:

The frame demonstrates the skills and knowledge in the engineering work practice divided into theory/practice and people/matter

The percentages are the share of survey respondents that selected the skills and knowledge

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

The frame is based on the engineering dimension framework of Figueiredo (2014, p.20)

(a.) Only the skills and knowledge constructs that received an above 30% selection were used for the frame

(b.) The upper part of the table shows the theory base of the practice and the lower the practice base of the work practice

(c.) The left side shows the people/society associated skills and knowledge and the right the matter/info

(d.) the sum indicated in each quarter of the frame is the sum of all percentages in that frame

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

However, the practice dimension seems slightly more relevant to perform the engineering practice of the engineering professionals working in the construction industry in my study. The latter supports an argument for learning in and through practise being relevant for professional learning. This is since skills and knowledge from each of these four quadrants were found in the survey results. Although skills and knowledge were found in all four quadrants, more skills as opposed to knowledge were selected in both practices which shifts the dimensional engineering framework more towards practice than towards theory.

The skills and knowledge survey results were aggregated into the four dimensions of engineering following the framework of Figueiredo (2014) is the result of this division for the work practice of *preparing project reports*. Namely, with theory, practice, people, and matter as the guidelines for the aggregations.

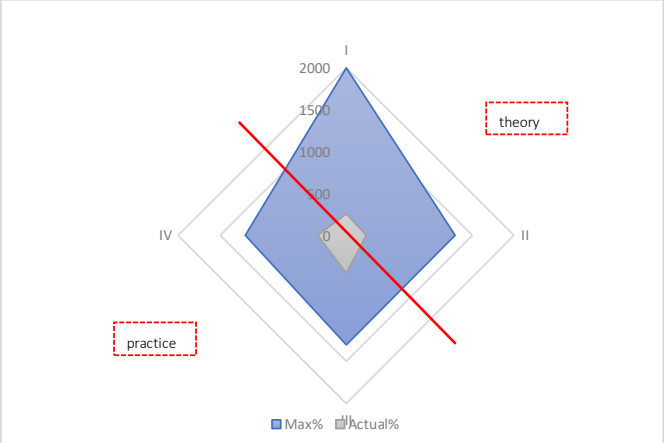
For example, on the side of knowledge, *engineering and construction* or *building and construction* were identified as belonging to science divisions and divided into the theory/matter quadrant whereas *economics*, *law*, and *English* were identified as belonging in social sciences and divided into the theory/people quadrant. What was left were the divisions of skills into the practice-based areas and therefore a distinction between matter and people was used in where, for example, *reading* was conceptualised as a *matter* issue rather than a *people* issue.

What can be seen from the framework in Figure 16 is that skills are indeed more significant for the work practice than knowledge, which is relevant for professional learning as the practice component of professional learning should receive more attention in that case. The higher share of the practical component is visible in the table above because the total percentage of skills is higher than the knowledge component. The sum of the lower left skills quadrant is 451% and the sum of the lower right skills quadrant is 333%, whereas the total percentages for knowledge were 259% in the upper left knowledge quadrant and 244% in the upper right knowledge qudrant. The latter two knowledge percentages are lower as opposed to those of the skills quadrants. If just focusing on the number of skills and knowledge items in each quadrant of the frame, the result can be simplified. The simplified framework and its divisions are shown in the frame in Figure 17.

Figure 17.

Skills and knowledge framework of work practice 1

SIMPLIFIED FRAMEWORK OF THE WORK PRACTICE OF PREPARING PROJECT REPORTS



Note:

The simplified framework demonstrates the skills and knowledge in the engineering work practice divided into theory/practice

The percentages are the share of survey respondents that selected the skills and knowledge

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

The frame is based on the engineering dimension framework of Figueiredo (2014, p.20)

(a.) Only the skills and knowledge constructs that received an above 30% selection were used for the frame

(b.) the sum of each quadrant was calculated based on the max percentage in the quadrant

(c.) I and III shows people/society quadrants and II and IV Matter/Info quadrants

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

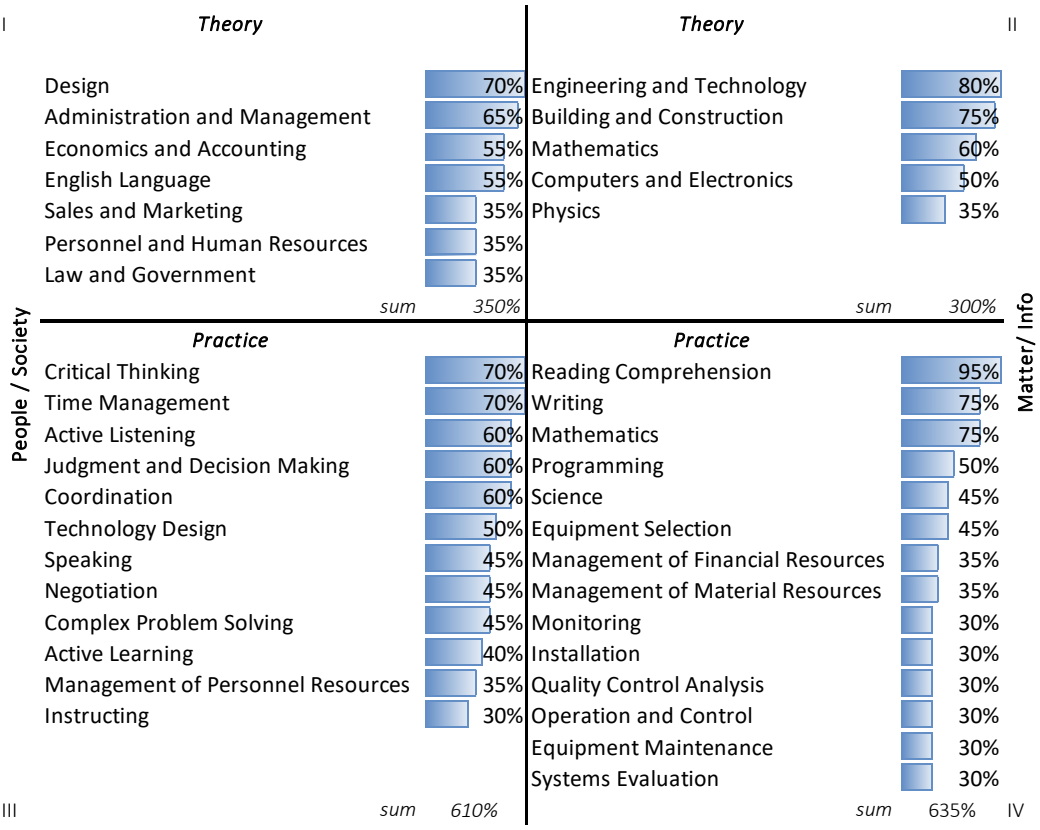
The resulting frame is the result of setting out the total percentages of each quadrant against the maximum possible score in that quadrant. The work of Gamble (2016) who used a frame to illustrate research results and the engineering dimension framework of Figueiredo (2014) inspired the development of this visual depiction. The grey area at the lower boundary of the red line shows that the practice component of engineering skills and knowledge is more significant than the theoretical part. The existence of the grey area in the plane above does, however, indicate that the theoretical part is relevant. This is important since professional learning for engineering practice should have a significant part of the skill practice component but should also need to address the theoretical knowledge base. Furthermore, professional learning for engineering practice may need to have a multi-disciplinary nature as it appears from the survey that the individual engineering knowledge is multi-disciplinary in both practices. By 'multi-disciplinary' I am not referring to different engineering disciplines but to the components found in the engineering dimension framework. The plane in Figure 16 shows that knowledge for the work practices is found in all disciplines, namely (1) social science knowledge such as *administration and management* (80%/65%) and *law and government* (33%/35%); (2) science knowledge such as *building and construction* (77%/75%), and *computers and electronics*

(47%/50%); design knowledge such as *critical thinking* (90%/70%), and *active learning* (47%/40%); and, lastly, skills found in craft knowledge such as *reading comprehension* (87%/95%) and *writing* (83%/75%).

Following the same approach as was done with the work practice of *preparing project reports*, for the work practice of *developing construction plans*, the engineering dimension frame of this work practice is shown in Figure 18 and the simplified dimensional framework is depicted in Figure 19.

Figure 18.

Engineering dimension frame for developing construction plans



Note:

The frame demonstrates the skills and knowledge in the engineering work practice divided into theory/practice and people/matter

The percentages are the share of survey respondents that selected the skills and knowledge

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

The frame is based on the engineering dimension framework of Figueiredo (2014, p.20)

(a.) Only the skills and knowledge constructs that received an above 30% selection were used for the frame

(b.) The upper part of the table shows the theory base of the practice and the lower the practice base of the work practice

(c.) The left side shows the people/society associated skills and knowledge and the right the matter/info

(d.) the sum indicated in each quarter of the frame is the sum of all percentages in that frame

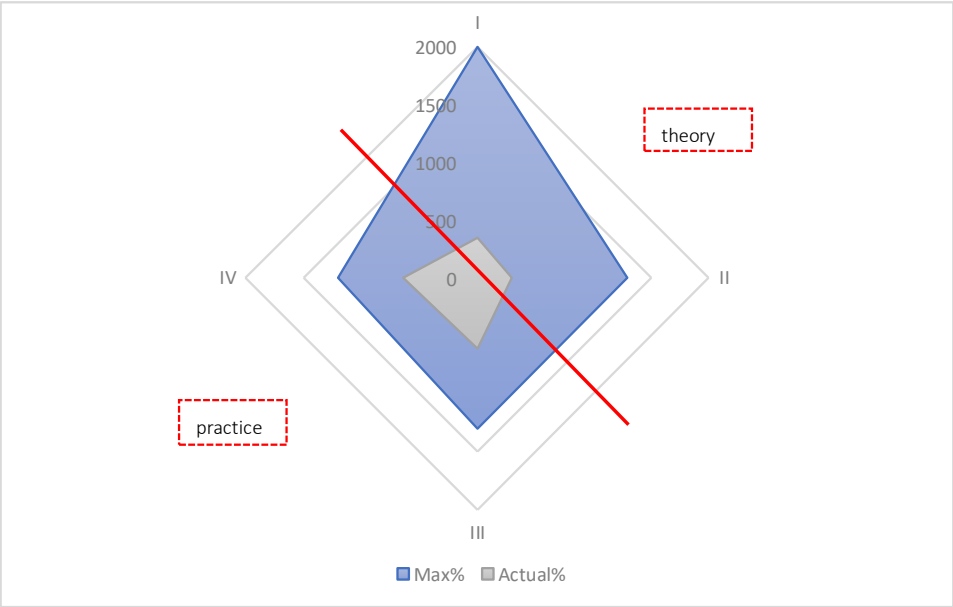
Source data: 2018-2019 STWL-survey (de Munnik, 2020)

An interesting appearance in the knowledge dimensions in the work practice of *developing construction plans* compared to *developing project reports* is that the share of both knowledge and skills seems to be increased in the work-task of *developing construction plans*. This latter practice is perceived as having more digital changes. In this practice, the skills selections were significantly more, which could illustrate that the two core work practices that are highly digitalized and changed can be associated with increased practicalities.

Figure 19.

Dimensions of enaineerina knowledae

SIMPLIFIED FRAMEWORK OF THE WORK PRACTICE OF DEVELOPING CONSTRUCTION PLANS



Note:

The simplified framework demonstrates the skills and knowledge in the engineering work practice divided into theory/practice

The percentages are the share of survey respondents that selected the skills and knowledge

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

The frame is based on the engineering dimension framework of Figueiredo (2014, p.20)

(a.) Only the skills and knowledge constructs that received an above 30% selection were used for the frame

(b.) the sum of each quadrant was calculated based on the max percentage in the quadrant

(c.) I and III shows people/society quadrants and II and IV Matter/Info quadrants

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

Since variances among professional engineering levels and countries appeared from the previous depiction of results relevant to the empirical results in this thesis, Table 9 is to highlight that for work skills and knowledge, variances between profesisonal levels and between countries exist.

Table 9.

Ten selected skills and variances in the work practices

The work related skills to be a member of the core engineering work practices of preparing project reports and developing construction plans

		Total				Australia			South Africa				United Arab Emirates			
Work skills		*Total*	*Technical*	*Engineering*	*Managing*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*
Work practice 1	Reading Comprehension	86.7%	50.0%	100.0%	88.9%	100.0%	100.0%	100.0%	100.0%	100.0%	83.3%	92.9%	0.0%	100.0%	100.0%	50.0%
(a.)	Active Listening	56.7%	66.7%	40.0%	77.8%	37.5%	100.0%	50.0%	100.0%	40.0%	66.7%	64.3%	33.3%	50.0%	100.0%	50.0%
	Writing	83.3%	50.0%	100.0%	77.8%	100.0%	100.0%	100.0%	100.0%	100.0%	66.7%	85.7%	0.0%	100.0%	100.0%	50.0%
	Speaking	50.0%	83.3%	26.7%	66.7%	25.0%	100.0%	40.0%	100.0%	20.0%	50.0%	50.0%	66.7%	50.0%	100.0%	66.7%
	Mathematics	40.0%	66.7%	26.7%	44.4%	12.5%	50.0%	20.0%	66.7%	40.0%	50.0%	50.0%	66.7%	50.0%	0.0%	50.0%
	Science	23.3%	16.7%	20.0%	33.3%	25.0%	0.0%	20.0%	33.3%	20.0%	50.0%	35.7%	0.0%	0.0%	0.0%	0.0%
	Critical Thinking	90.0%	66.7%	93.3%	100.0%	87.5%	100.0%	90.0%	100.0%	100.0%	100.0%	100.0%	33.3%	100.0%	100.0%	66.7%
	Active Learning	46.7%	83.3%	40.0%	33.3%	37.5%	0.0%	30.0%	100.0%	40.0%	33.3%	50.0%	66.7%	50.0%	100.0%	66.7%
	Learning Strategies	16.7%	16.7%	20.0%	11.1%	25.0%	0.0%	20.0%	33.3%	0.0%	0.0%	7.1%	0.0%	50.0%	100.0%	33.3%
	Monitoring	40.0%	83.3%	13.3%	55.6%	0.0%	50.0%	10.0%	66.7%	20.0%	66.7%	50.0%	100.0%	50.0%	0.0%	66.7%
Work practice 2	Reading Comprehension	95.0%	100.0%	100.0%	80.0%	100.0%		100.0%	100.0%	100.0%	75.0%	92.3%	100.0%		100.0%	100.0%
(b.)	Active Listening	60.0%	80.0%	50.0%	60.0%	80.0%		80.0%	100.0%	20.0%	50.0%	53.8%	0.0%		100.0%	50.0%
	Writing	75.0%	80.0%	80.0%	60.0%	100.0%		100.0%	75.0%	60.0%	50.0%	61.5%	100.0%		100.0%	100.0%
	Speaking	45.0%	80.0%	40.0%	20.0%	60.0%		60.0%	75.0%	20.0%	25.0%	38.5%	100.0%		0.0%	50.0%
	Mathematics	75.0%	60.0%	90.0%	60.0%	100.0%		100.0%	75.0%	80.0%	75.0%	76.9%	0.0%		0.0%	0.0%
	Science	45.0%	80.0%	30.0%	40.0%	40.0%		40.0%	75.0%	20.0%	50.0%	46.2%	100.0%		0.0%	50.0%
	Critical Thinking	70.0%	80.0%	80.0%	40.0%	60.0%		60.0%	100.0%	100.0%	50.0%	84.6%	0.0%		0.0%	0.0%
	Active Learning	40.0%	60.0%	50.0%	0.0%	40.0%		40.0%	50.0%	60.0%	0.0%	38.5%	100.0%		0.0%	50.0%
	Learning Strategies	25.0%	40.0%	10.0%	40.0%	20.0%		20.0%	50.0%	0.0%	25.0%	23.1%	0.0%		100.0%	50.0%
	Monitoring	30.0%	80.0%	10.0%	20.0%	20.0%		20.0%	75.0%	0.0%	0.0%	23.1%	100.0%		100.0%	100.0%

Note:

These two tables demonstrate the required skills to be a member of the respective core engineering work practices based on the survey results

The percentages (%) are the share of survey respondents that selected the answer option in the respective survey question

The tables are based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

*The skills constructs in the survey were based upon the 35 O*Net skills*

(a.) The upper part of the table shows the perceived skills in the work practice of preparing project reports (N=30)

(b.) The lower part of the table shows the perceived skills in the work practice of developing construction plans (N=20)

(c.) To make variances visible among the professional engineering levels and countries, conditional formatting in MS Excel was applied

(d.) The skills were gathered by posing the question: I need the following skills to perform the work-task successfully… (click all that are relevant)

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

What can be seen the table, by following the horizontal similarity of colouring and between the upper and lower part of the table is that the some of the work skill selections in the survey showed similarity and consistency across professional levels, countries and between the two core engineering work practices while others showed more variety. For example, selections of reading comprehension are consistent across professional levels, countries and between work practices but writing is more or less consistent in work practice 1 but already shows more variance in engineering and managing professionals in South Africa. Also, while active listening is regarderd among engineering respondents in work practice 2 as important for the Australian engineers, it is not regarded as important for South African engineers. Surprisingly, the same skill is regarded much lower among Australian engineering professionals that opted for work practice 1, namely a difference from 80% to 38% which is significant. The main point which can be made based on these survey results is

that work skill variances across engineering professional levels and countries and between engineering core work practices emerge. A similar picture emerged for the work knowledge in both work practices but is not illustrated with a table here since the picture is similar.

6.5.2 Disciplinary engineering knowledge and general skills are related.

A cross-tabulation in IBM SPSS-25 (See APPENDIX H-DATA GENERATION PROCEDURE IBM-SPSS-25) on the work skills and knowledge showed that disciplinary engineering knowledge and general skills were correlated as can be seen in Table 10 for the work practice of *preparing project reports.*

Table 10.

Crosstabulation skills*knowledge in work practice 1

CROSSTAB INDIVIDUAL WORKKNOWLEDGE * WORKSKILLS IN WORK PRACTICE PREPARING PROJECT REPORTS (% N=30)

Workskills	Administration and Management	Clerical	Economics and Accounting	Sales and Marketing	Customer and Personal Service	Personnel and Human Resources	Computers and Electronics	Engineering and Technology	Design	Building and Construction	Mechanical	Mathematics	Physics	Education and Training	English Language	Public Safety and Security	Law and Government	Telecommunications	Communications and Media
Reading Comprehension	70%	13%	33%	13%	27%	17%	43%	70%	63%	67%	20%	33%	23%	17%	47%	17%	33%	20%	17%
Active Listening	50%	3%	27%	13%	27%	17%	30%	43%	40%	50%	10%	20%	17%	13%	33%	17%	30%	13%	13%
Writing	67%	13%	33%	13%	27%	17%	40%	67%	60%	63%	20%	33%	23%	17%	47%	17%	33%	20%	17%
Speaking	47%	7%	30%	13%	27%	17%	27%	37%	30%	40%	7%	23%	17%	7%	30%	13%	23%	17%	13%
Mathematics	33%	10%	23%	10%	20%	13%	17%	30%	27%	33%	7%	30%	13%	3%	20%	13%	17%	13%	7%
Science	20%	3%	17%	10%	13%	10%	10%	17%	17%	20%	7%	13%	13%	3%	13%	7%	7%	7%	7%
Critical Thinking	73%	17%	33%	13%	27%	17%	40%	70%	63%	70%	20%	40%	23%	17%	43%	17%	33%	20%	17%
Active Learning	33%	3%	13%	3%	13%	7%	23%	37%	27%	37%	10%	27%	13%	13%	23%	7%	17%	13%	13%
Learning Strategies	17%	0%	13%	3%	10%	7%	10%	13%	13%	13%	3%	10%	7%	0%	7%	3%	7%	3%	3%
Monitoring	37%	10%	13%	10%	17%	7%	20%	30%	23%	33%	7%	20%	10%	7%	20%	10%	20%	13%	17%
Social Perceptiveness	17%	0%	13%	7%	10%	10%	10%	17%	17%	17%	10%	13%	13%	7%	13%	10%	13%	7%	3%
Coordination	43%	7%	13%	3%	17%	7%	20%	37%	30%	37%	13%	23%	13%	7%	37%	10%	17%	7%	3%
Persuasion	13%	3%	10%	7%	10%	3%	3%	10%	10%	13%	3%	7%	3%	0%	7%	7%	10%	3%	3%
Negotiation	30%	13%	20%	10%	13%	7%	17%	27%	23%	27%	7%	20%	10%	3%	13%	10%	17%	13%	10%
Instructing	10%	3%	7%	3%	7%	3%	7%	13%	13%	10%	3%	10%	7%	3%	10%	7%	13%	7%	3%
Complex Problem Solving	37%	13%	20%	3%	13%	7%	20%	33%	30%	27%	13%	20%	13%	13%	20%	13%	20%	13%	3%
Operations Analysis	17%	3%	7%	7%	10%	7%	7%	17%	17%	17%	7%	10%	10%	0%	13%	10%	10%	7%	3%
Technology Design	13%	3%	10%	3%	7%	7%	7%	13%	10%	10%	7%	10%	10%	3%	10%	7%	7%	7%	0%
Equipment Selection	23%	10%	10%	7%	10%	7%	13%	23%	20%	20%	10%	13%	13%	3%	20%	10%	10%	13%	7%
Installation	13%	3%	3%	3%	3%	3%	10%	13%	7%	13%	3%	7%	3%	3%	7%	3%	3%	7%	7%
Programming	13%	0%	7%	7%	10%	3%	7%	7%	7%	17%	0%	7%	3%	0%	7%	3%	7%	3%	10%
Quality Control Analysis	20%	7%	7%	7%	10%	3%	10%	17%	17%	20%	7%	10%	7%	10%	10%	10%	10%	10%	10%
Operations Monitoring	17%	7%	7%	7%	10%	3%	10%	13%	10%	17%	3%	7%	3%	3%	10%	7%	7%	10%	10%
Operation and Control	17%	3%	7%	7%	7%	3%	10%	13%	7%	17%	3%	7%	3%	3%	7%	3%	3%	7%	10%
Troubleshooting	17%	7%	3%	0%	7%	3%	10%	17%	10%	17%	7%	10%	3%	7%	10%	7%	7%	10%	3%
Judgment and Decision Making	43%	7%	27%	13%	17%	13%	20%	30%	30%	37%	13%	20%	13%	10%	17%	13%	20%	7%	7%
Time Management	57%	7%	27%	13%	23%	13%	30%	53%	47%	57%	13%	30%	20%	13%	43%	17%	33%	13%	13%
Management of Financial Resources	33%	7%	17%	7%	20%	10%	13%	27%	27%	30%	13%	17%	13%	10%	20%	17%	23%	10%	7%
Management of Material Resources	17%	3%	10%	7%	10%	7%	7%	13%	13%	17%	7%	7%	7%	0%	10%	7%	13%	3%	7%
Management of Personnel Resources	30%	3%	13%	7%	17%	7%	10%	23%	23%	27%	10%	13%	10%	7%	17%	13%	20%	7%	7%

Note:

The table demonstrates the association between knowledge and the skills to be a member of the practices

The % are based on the survey respondents that selected the answer options in the respective survey questions

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

*The skills and knowledge constructs in the survey were based on the 35 O*Net skills and 33 knowledge*

(a.) Crosstabulation between skills in work practice and practice are calculated with IBM SPSS-25 on non-missing values in work practice 'prepare reports…'

(b.) Percentages are calculated in MS Excel as % of total work practice (N=30)

(c.) Rows and columns with 10% or below are removed to synthesize the table

(d.) The skills and knowledge were gathered by posing the questions: I need the following skills/knowledge to perform the work-task successfully… (click all that are relevant)

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

Table 10 shows that there is a strong correlation between disciplinary engineering knowledge and general skills. For example, *building and construction* knowledge is highly correlated with *critical thinking skills* (70%) but also with *reading comprehension* (63%). Also, *engineering and technology* knowledge is highly correlated with both *critical thinking* (70%) and *reading comprehension* (70%). In addition to engineering-specific knowledge, the knowledge found in other disciplines such as *administration and management* also shows high correlations with, for example, *critical thinking* (73%) and *reading comprehension* (70%). This could indicate that as an individual member of this engineering practice it is essential to practice skills and knowledge in these different discipline-specific and multidisciplinary areas. This is thus, essential for professional learning to consider when addressing learning for work. The skills and knowledge for the work practice of developing construction plans were also cross-tabulated to see if there were some associations between selections of particular skills and knowledge visible. Table 11 is the result of this cross-tabulation.

Table 11.

*Cross tabulation skills*knowledge in work practice 2*

CROSSTAB INDIVIDUAL WORK KNOWLEDGE * WORK SKILLS IN THE WORK PRACTICE DEVELOPING CONSTRUCTION PLANS (% N=20)

Workskills	Administration and Management	Clerical	Economics and Accounting	Sales and Marketing	Customer and Personal Service	Personnel and Human Resources	Production and Processing	Computers and Electronics	Engineering and Technology	Design	Building and Construction	Mechanical	Mathematics	Physics	Sociology and Anthropology	Education and Training	English Language	Public Safety and Security	Law and Government	Telecommunications	Communications and Media
Reading Comprehension	65%	15%	55%	35%	20%	35%	25%	50%	80%	70%	70%	25%	60%	35%	15%	15%	55%	20%	35%	20%	20%
Active Listening	40%	5%	40%	20%	15%	25%	15%	30%	55%	45%	45%	15%	40%	30%	10%	10%	30%	15%	25%	5%	15%
Writing	55%	10%	40%	25%	20%	30%	20%	45%	70%	60%	55%	25%	55%	30%	15%	15%	50%	20%	30%	15%	15%
Speaking	35%	5%	30%	20%	20%	25%	25%	30%	40%	30%	35%	15%	30%	25%	10%	10%	30%	15%	20%	15%	10%
Mathematics	45%	10%	40%	25%	20%	25%	15%	40%	65%	55%	60%	25%	60%	35%	10%	5%	50%	20%	35%	10%	10%
Science	45%	10%	30%	30%	20%	20%	20%	30%	35%	30%	35%	20%	30%	30%	10%	10%	35%	20%	25%	15%	10%
Critical Thinking	50%	15%	50%	30%	20%	25%	20%	45%	60%	55%	55%	20%	55%	35%	10%	5%	45%	20%	35%	15%	15%
Active Learning	30%	5%	20%	15%	10%	10%	15%	25%	30%	35%	35%	5%	25%	15%	0%	10%	30%	5%	15%	15%	15%
Learning Strategies	25%	0%	15%	10%	10%	15%	10%	15%	20%	20%	20%	5%	20%	15%	5%	10%	15%	5%	10%	5%	15%
Monitoring	30%	5%	20%	15%	10%	15%	15%	20%	25%	25%	25%	10%	20%	20%	5%	15%	25%	10%	15%	10%	15%
Coordination	40%	10%	30%	25%	20%	25%	20%	35%	50%	50%	50%	20%	50%	30%	10%	10%	45%	15%	25%	20%	15%
Negotiation	40%	5%	30%	20%	15%	25%	20%	25%	40%	35%	40%	15%	30%	25%	10%	15%	30%	15%	20%	10%	15%
Instructing	25%	5%	20%	10%	5%	10%	15%	20%	25%	25%	30%	10%	20%	15%	0%	10%	25%	5%	15%	10%	5%
Complex Problem Solving	35%	10%	35%	20%	15%	20%	15%	25%	35%	40%	45%	15%	35%	25%	10%	5%	30%	10%	25%	15%	10%
Technology Design	35%	10%	25%	20%	15%	20%	15%	30%	40%	45%	40%	20%	40%	20%	10%	10%	40%	10%	20%	20%	10%
Equipment Selection	35%	10%	30%	25%	15%	20%	20%	30%	35%	35%	40%	15%	30%	25%	5%	10%	30%	15%	20%	15%	15%
Installation	30%	15%	25%	25%	15%	15%	15%	25%	25%	30%	30%	15%	20%	20%	10%	10%	25%	15%	20%	20%	10%
Programming	40%	10%	35%	25%	15%	25%	20%	30%	40%	35%	45%	10%	25%	20%	10%	15%	25%	15%	20%	15%	20%
Quality Control Analysis	25%	5%	25%	15%	10%	10%	10%	20%	25%	25%	30%	10%	30%	25%	0%	5%	30%	10%	25%	5%	10%
Operation and Control	25%	5%	20%	15%	15%	20%	25%	20%	25%	20%	30%	10%	20%	20%	5%	10%	25%	10%	15%	15%	10%
Equipment Maintenance	25%	5%	25%	20%	20%	25%	25%	20%	30%	20%	30%	10%	20%	20%	10%	10%	25%	15%	20%	15%	10%
Systems Evaluation	30%	10%	20%	20%	10%	10%	5%	20%	20%	30%	30%	15%	25%	20%	5%	5%	20%	10%	15%	10%	10%
Judgment and Decision Making	45%	10%	35%	20%	15%	30%	20%	30%	55%	50%	50%	25%	45%	25%	15%	15%	45%	15%	25%	15%	10%
Time Management	40%	10%	35%	20%	15%	25%	25%	40%	65%	55%	60%	20%	55%	30%	5%	10%	50%	15%	30%	15%	10%
Management of Financial Resources	25%	10%	30%	20%	15%	25%	20%	25%	35%	20%	35%	15%	30%	20%	5%	5%	30%	15%	25%	10%	10%
Management of Material Resources	30%	10%	30%	20%	15%	20%	20%	25%	30%	25%	35%	15%	30%	25%	5%	5%	30%	15%	25%	10%	10%
Management of Personnel Resources	25%	10%	25%	15%	10%	20%	15%	20%	30%	25%	35%	20%	30%	20%	5%	5%	30%	10%	20%	10%	5%

Note:

The table demonstrates the association between knowledge and the skills to be a member of the practice

The % are based on the survey respondents that selected the answer options in the respective survey questions
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

*The skills and knowledge constructs in the survey were based on the 35 O*Net skills and 33 knowledge*
(a.) Crosstabulation between skills in work practice and practice are calculated with IBM SPSS-25 on non-missing values in work practice developing construction plans

(b.) Percentages are calculated in MS Excel as % of total work practice (N=20)

(c.) Rows and columns with 10% or below are removed to synthesize the table
(d.) The skills and knowledge were gathered by posing the questions: I need the following skills/knowledge to perform the work-task successfully… (click all that are relevant)

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The first thing that Table 11 shows is that this work practice shows less diversity in the associations between skills and knowledge than the work practice of *preparing project reports* and stronger associations. This can be seen by looking at the density and spread of blue colours as well as the high percentages in the blue areas. The table also shows that disciplinary engineering knowledge and general skills are associated. It appears as if the diversity in this practice is more spread across different engineering dimensions in where social skills such as administration and management and English are strongly correlated to this disciplinary knowledge aspect. What can be seen above is that with the same techniques being applied to the skills category, a less diverse picture seems to emerge. What appears from the tables to stay the same is that almost double the amount of the selection of knowledge and learning correlates in the work-task of *developing construction plans*. It might be that the formal knowledge base of this work task is stronger than that of the work task *preparing project reports* which is consistent with the findings before. At the same time, this second work practice was also the work practice being more digitalised so an emerging topic for future exploration in research would be to focus on this association.

Since variances between professional engineering levels appeared relevant so far, Table 12 shows the variances among the three engineering professional levels between engineering and technology knowledge associated with work skills for both selected core engineering work practices.

Table 12.

Association between engineering knowledge and skills in work practices

ENGINEERING AND TECHNOLOGY KNOWLEDGE * SKILLS IN BOTH WORK PRACTICES * PROFESSIONAL GROUP CROSSTABULATION

		Work practice 1				Work practice 2			
		Engineering and technology knowledge				Engineering and technology knowledge			
		Total	Technical	Engineering	Managing	Total	Technical	Engineering	Managing
Work skills	**Reading comprehension**	21	3	14	4	16	5	8	3
	Active listening	13	4	6	3	11	4	4	3
	Writing	20	3	14	3	14	4	7	3
	Speaking	11	5	4	2	8	4	3	1
	Mathematics	9	3	4	2	13	3	8	2
	Science	5	1	3	1	7	4	2	1
	Critical thinking	21	3	14	4	12	4	6	2
	Active learning	11	5	0	6	6	3	3	0
	Learning strategies	4	1	3	0	4	2	0	2
	Monitoring	9	4	2	3	5	4	0	1
	Social perceptiveness	5	2	2	1	4	4	0	0
	Coordination	11	2	6	3	10	3	5	2
	Persuasion	3	0	1	2	2	1	0	1
	Negotiation	8	1	3	3	8	5	0	3
	Instructing	4	1	1	2	5	4	1	0
	Service orientation	3	1	0	2	2	1	1	0
	Complex problem solving	10	1	6	3	7	2	3	2
	Operations analysis	5	1	1	3	4	3	0	1
	Technology design	4	2	1	1	8	2	5	1
	Equipment selection	7	2	3	2	7	5	1	1
	Installation	4	3	1	0	5	3	1	1
	Programming	2	1	0	1	8	5	0	3
	Quality control	5	1	3	1	5	3	2	0
	Operations monitoring	4	2	1	1	3	3	0	0
	Operation and control	4	3	1	0	5	4	1	0
	Equipment maintenance	2	2	0	0	6	4	1	1
	Troubleshooting	5	3	1	1	2	2	0	0
	Repairing	3	2	1	0	2	2	0	0
	Systems analysis	2	1	1	0	3	1	1	1
	Systems evaluation	2	1	1	0	4	2	0	2
	Judgement and decision making	9	2	5	2	11	4	4	3
	Time management	16	4	8	4	13	5	7	1
	Management financial resources	8	2	3	3	7	4	3	0
	Management material resources	4	1	1	2	6	4	2	0
	Management personal resources	7	1	4	2	6	3	3	0
	total								

Note:

The table demonstrates the association between engineering and technology knowledge and the skills to be a member of the practices

The counts are the survey respondents that selected the answer options in the respective survey questions

The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

*The skills and knowledge constructs in the survey were based upon the 35 O*Net skills and 33 knowledge*

(a.) The left part of the table shows the work practice of preparing project reports (N=30)

(b.) The right part of the table shows the work practice of developing construction plans (N=20)

(c.) To make variances visible among the professional engineering levels, conditional formatting in MS Excel was applied. Black boxes illustrate the main variances

(d.) The skills and knowledge were gathered by posing the questions: I need the following skills/knowledge to perform the work-task successfully… (click all that are relevant)

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The table shows that variances between professional engineering levels exist. Variances between engineering and technical but also between managing and engineering are illustrated with the table. The bold skills on the left were at the same time the skills which were associated to work with digital technologies and may indicate the skill/knowledge variances among professional engineering levels which enable them to *enact* upon digital technology exist.

6.5.3 Digital technologies require general skills.

The different skills and knowledge selected in the survey to work with digital technologies revealed that more engineering discipline specific skills and knowledge were key, as opposed to the skills and knowledge selected to do the work practice without referring to the digital. It also appeared that there were variances between higher and lower level professionals in skills used which can indicate the differences in usage of digital technologies in their work and their capabilities.

Table 13 and Table 14 show the skills and knowledge to work with digital technologies in the work practices. Due to the loop and merge structure of the survey, the question about digital technology skills and knowledge was explicitly relating to the selected work practices and the selection of specific digital technologies in those work practices. As such, the tables only reflects the percentual share of the participants that selected the work practices in their survey. The percentual share was calculated to tell the story because absolute numbers would have been skewed as the three groups were not similar in size. This percentual number, however, is only for descriptive purposes and not for any statistical purposes.

Table 13.

Knowledge to work with digital technologies in work task prepare reports

DIGITAL TECHNOLOGY KNOWLEDGE OF MEDIUM TO HIGHER SKILLED CONSTRUCTION ENGINEERING PROFESSIONALS

		Work practice 1 (a.)				**Work practice 2 (b.)**			
		Engineering and technology knowledge				Engineering and technology knowledge			
		Total	Technical	Engineering	Managing	Total	Technical	Engineering	Managing
Digital knowledge	Admin	50.0%	83.3%	33.3%	55.6%	50.0%	100.0%	30.0%	40.0%
(c./d.)	clerical	3.3%	16.7%	0.0%	0.0%	5.0%	20.0%	0.0%	0.0%
	economics	10.0%	16.7%	0.0%	22.2%	25.0%	40.0%	0.0%	60.0%
	sales	6.7%	16.7%	0.0%	11.1%	15.0%	20.0%	0.0%	40.0%
	Customerservice	10.0%	0.0%	0.0%	33.3%	5.0%	0.0%	0.0%	20.0%
	HR	10.0%	33.3%	6.7%	0.0%	20.0%	60.0%	10.0%	0.0%
	Production	16.7%	66.7%	6.7%	0.0%	25.0%	80.0%	10.0%	0.0%
	FoodPr	3.3%	16.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Computers	73.3%	50.0%	93.3%	55.6%	70.0%	60.0%	80.0%	60.0%
	EngTech	80.0%	66.7%	93.3%	66.7%	85.0%	60.0%	100.0%	80.0%
	design	70.0%	33.3%	93.3%	55.6%	60.0%	20.0%	90.0%	40.0%
	Construction	70.0%	50.0%	73.3%	77.8%	70.0%	60.0%	80.0%	60.0%
	mechanical	33.3%	50.0%	40.0%	11.1%	25.0%	40.0%	30.0%	0.0%
	mathematics	40.0%	0.0%	60.0%	33.3%	40.0%	20.0%	50.0%	40.0%
	physics	16.7%	0.0%	26.7%	11.1%	20.0%	0.0%	30.0%	20.0%
	geography	3.3%	0.0%	6.7%	0.0%	5.0%	0.0%	10.0%	0.0%
	education	3.3%	16.7%	0.0%	0.0%	10.0%	20.0%	0.0%	20.0%
	English	20.0%	16.7%	20.0%	22.2%	25.0%	40.0%	20.0%	20.0%
	Security	10.0%	33.3%	6.7%	0.0%	15.0%	40.0%	10.0%	0.0%
	Law	3.3%	16.7%	0.0%	0.0%	5.0%	20.0%	0.0%	0.0%
	telecommunications	6.7%	16.7%	0.0%	11.1%	10.0%	20.0%	10.0%	0.0%
	Media	16.7%	33.3%	0.0%	33.3%	10.0%	20.0%	0.0%	20.0%
	transportation	3.3%	16.7%	0.0%	0.0%	5.0%	20.0%	0.0%	0.0%
	total	168	39	84	45	*120*	*38*	*56*	*26*
	cases	30	6	15	9	*20*	*5*	*10*	*5*

Note:

The table demonstrates the digital knowledge required to be a member of the practices

The counts are the survey respondents that selected the answer options in the respective survey questions
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

*The skills and knowledge constructs in the survey were based upon the 35 O*Net skills and 33 knowledge*

(a.) 30 valid cases, Baseline for % calculation are cases

(b.) 20 valid cases, Baseline for % calculation are cases
(c.) Only the previously selected digital technologies appeared in the respective survey question which is argued to be explicit to the respondent

(d.) The skills and knowledge were gathered by posing the questions:
Please, select the 5 to 10 most important knowledge fields that you need to work with the digital technologies you use in your work

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

Table 14.

Skills to work with digital technologies in work practice develop plans

DIGITAL TECHNOLOGY SKILLS OF MEDIUM TO HIGHER SKILLED CONSTRUCTION ENGINEERING PROFESSIONALS

		Work practice 1 (a.)				Work practice 2 (b.)			
		Engineering and technology knowledge				Engineering and technology knowledge			
		Total	Technical	Engineering	Managing	Total	Technical	Engineering	Managing
Digital skills	Reading	50.0%	16.7%	53.3%	66.7%	65.0%	40.0%	70.0%	80.0%
(c./d.)	Listening	13.3%	33.3%	0.0%	22.2%	15.0%	40.0%	10.0%	0.0%
	Writing	16.7%	16.7%	20.0%	11.1%	25.0%	20.0%	30.0%	20.0%
	Speaking	6.7%	0.0%	13.3%	0.0%	15.0%	0.0%	20.0%	20.0%
	Maths	33.3%	33.3%	40.0%	22.2%	35.0%	40.0%	30.0%	40.0%
	Science	20.0%	16.7%	26.7%	11.1%	20.0%	20.0%	20.0%	20.0%
	Critical Thinking	70.0%	33.3%	93.3%	55.6%	70.0%	20.0%	100.0%	60.0%
	Active Learning	50.0%	16.7%	73.3%	33.3%	55.0%	20.0%	90.0%	20.0%
	Learning Strategies	20.0%	16.7%	13.3%	33.3%	30.0%	20.0%	30.0%	40.0%
	Monitoring	10.0%	33.3%	6.7%	0.0%	5.0%	20.0%	0.0%	0.0%
	Perceptiveness	6.7%	16.7%	0.0%	11.1%	10.0%	20.0%	0.0%	20.0%
	Coordination	30.0%	66.7%	26.7%	11.1%	30.0%	60.0%	20.0%	20.0%
	Persuasion	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Negotiation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Instructing	3.3%	0.0%	6.7%	0.0%	0.0%	0.0%	0.0%	0.0%
	Service Orientation	6.7%	16.7%	6.7%	0.0%	10.0%	20.0%	10.0%	0.0%
	Problem Solving	36.7%	16.7%	60.0%	11.1%	45.0%	40.0%	70.0%	0.0%
	Operation Analysis	10.0%	16.7%	6.7%	11.1%	20.0%	20.0%	20.0%	20.0%
	Technology Design	36.7%	0.0%	46.7%	44.4%	40.0%	0.0%	60.0%	40.0%
	Selection	20.0%	33.3%	13.3%	22.2%	25.0%	20.0%	20.0%	40.0%
	Installation	13.3%	33.3%	6.7%	11.1%	10.0%	20.0%	0.0%	20.0%
	Programming	26.7%	50.0%	26.7%	11.1%	30.0%	60.0%	20.0%	20.0%
	QC analysis	6.7%	16.7%	6.7%	0.0%	10.0%	20.0%	10.0%	0.0%
	Operation Monitoring	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Operation Control	3.3%	16.7%	0.0%	0.0%	5.0%	20.0%	0.0%	0.0%
	Maintenance	10.0%	33.3%	6.7%	0.0%	10.0%	20.0%	0.0%	20.0%
	Troubleshooting	20.0%	16.7%	33.3%	0.0%	20.0%	20.0%	30.0%	0.0%
	Repairing	10.0%	33.3%	0.0%	11.1%	10.0%	20.0%	0.0%	20.0%
	System Analysis	20.0%	16.7%	20.0%	22.2%	10.0%	20.0%	0.0%	20.0%
	System Evaluation	13.3%	16.7%	20.0%	0.0%	10.0%	20.0%	10.0%	0.0%
	Decision Making	33.3%	16.7%	33.3%	44.4%	20.0%	20.0%	20.0%	20.0%
	Time Management	20.0%	33.3%	20.0%	11.1%	20.0%	60.0%	10.0%	0.0%
	Management Fin Res	6.7%	0.0%	6.7%	11.1%	5.0%	20.0%	0.0%	0.0%
	Management Mat Res	6.7%	16.7%	0.0%	11.1%	5.0%	20.0%	0.0%	0.0%
	Management Pers Res	3.3%	0.0%	0.0%	11.1%	5.0%	20.0%	0.0%	0.0%
	Other	10.0%	0.0%	0.0%	33.3%	10.0%	0.0%	0.0%	40.0%
	total	*193*	*41*	*103*	*49*	*139*	*39*	*70*	*30*
	cases	*30*	*6*	*15*	*9*	*20*	*5*	*10*	*5*

Note:

The table demonstrates the digital skills required to be a member of the practices

The counts are the survey respondents that selected the answer options in the respective survey questions
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

*The skills and knowledge constructs in the survey were based upon the 35 O*Net skills and 33 knowledge*

(a.) 30 valid cases, Baseline for % calculation are cases

(b.) 20 valid cases, Baseline for % calculation are cases

(c.) Only the previously selected digital technologies appeared in the respective survey question which is argued to be explicit to the respondent

(d.) The skills and knowledge were gathered by posing the questions:
Please, select the 5 to 10 most important knowledge fields that you need to work with the digital technologies you use in your work

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

Table 14 shows on the right that besides more technical skills such as systems analysis, also general skills are required to work with digital technology. Respondent agreement is perceived when all three workgroups are the same colour. This is however only the case for the general skills such as *reading*, *active learning* and *critical thinking*, and it is the case for technical skill such as *systems analysis*. Disagreement is apparent in the skills table on the right and for example programming and systems evaluation seems more important for technical and engineering professionals. Another technical focused disagreement seems to focus on *science*, which is not perceived as important among the management group but that perhaps makes sense because they are not always *performing* technical or engineering work themselves. Another disagreement is more surprising and that is technology design which is not selected among technical professionals but more among engineering and managing professionals and can indicate that the role of digital technologies in work centres more on the process side as opposed to the tools side. For decision making skills, although there is some respondent agreement, shows a similar result what may have to do with the more 'sophisticated' kind of digital technologies used in the work. On the other hand, the knowledge areas on the left almost appear to be significantly less in terms of total selections as compared to the skills. The selection of knowledge items such as mechanical, production and processing are easy to grasp in the context of working with digital technology but then the selection of media and communication is less straightforward to grasp. Respondent agreement centres around items such as disciplinary knowledge areas, such as *construction and engineering*, *technology design* and *administration* whereas disagreement was found more among technical and engineering staff for mechanical knowledge. Mathematics was another disagreement item and seemed to be perceived as more important for engineering and managing professionals.

Since variances are important to discuss in this thesis, Table 15 illustrates the variances among countries and engineering levels for the digital skills that were selected in the survey.

Table 15.

Ten digital skills required for work practice 1

The digital skills required to be a member of the core engineering work practice of preparing project reports

		Total	Australia					South Africa				United Arab Emirates				
Digital skills		*Total*	*Technical*	*Engineering*	*Managing*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*
Digital skills	Reading	50.0%	16.7%	53.3%	66.7%	50.0%	50.0%	50.0%	33.3%	80.0%	66.7%	64.3%	0.0%	0.0%	100.0%	16.7%
(a.)	Listening	13.3%	33.3%	0.0%	22.2%	0.0%	0.0%	0.0%	66.7%	0.0%	16.7%	21.4%	0.0%	0.0%	100.0%	16.7%
	Writing	16.7%	16.7%	20.0%	11.1%	12.5%	50.0%	20.0%	33.3%	40.0%	0.0%	21.4%	0.0%	0.0%	0.0%	0.0%
	Speaking	6.7%	0.0%	13.3%	0.0%	25.0%	0.0%	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Maths	33.3%	33.3%	40.0%	22.2%	25.0%	0.0%	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Science	20.0%	16.7%	26.7%	11.1%	25.0%	0.0%	20.0%	33.3%	20.0%	16.7%	21.4%	0.0%	100.0%	0.0%	33.3%
	Critical Thinking	70.0%	33.3%	93.3%	55.6%	87.5%	100.0%	90.0%	33.3%	100.0%	33.3%	57.1%	33.3%	100.0%	100.0%	66.7%
	Active Learning	50.0%	16.7%	73.3%	33.3%	75.0%	0.0%	60.0%	33.3%	100.0%	33.3%	57.1%	0.0%	0.0%	100.0%	16.7%
	Learning Strategies	20.0%	16.7%	13.3%	33.3%	12.5%	50.0%	20.0%	33.3%	20.0%	16.7%	21.4%	0.0%	0.0%	100.0%	16.7%
	Monitoring	10.0%	33.3%	6.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	66.7%	50.0%	0.0%	50.0%
	* the remaining 25 skills are not depicted here															
	total	*193*	*41*	*103*	*49*	*44*	*11*	*55*	*19*	*40*	*30*	*89*	*20*	*17*	*5*	*42*
	cases	*30*	*6*	*15*	*9*	*8*	*2*	*10*	*3*	*5*	*6*	*14*	*3*	*2*	*1*	*6*

Note:
The table demonstrate the required digital skills to be a member of the respective core engineering work practice based on the survey results
The percentages (%) are the share of survey respondents that selected the answer option in the respective survey question
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

*The skills constructs in the survey were based on the 35 O*Net skills*

(a.) The table shows the perceived skills in the work practice of preparing project reports (N=30)
(b.) To make variances visible among the professional engineering levels and countries, conditional formatting in MS Excel was applied
(c.) The digital skills were gathered by posing the question: Please, select the 5 to 10 most important skills that you need to work with the digital technologies in your work (click 5 to 10)

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

6.5.4 Variances in technical skill demands and the value of general skills.

The different skills and knowledge selected in the survey to work with digital technologies revealed that more engineering discipline specific skills and knowledge were key, as opposed to the skills and knowledge selected to do the work practice without referring to the digital. It also appeared that there were variances between higher- and lower-level professionals in skills used which can indicate the differences in the use of digital technologies in their work and their capabilities. Table 16 shows the skills and knowledge to work with digital technologies in the work task *preparing project reports*. The table shows on the right that besides more technical skills such as systems analysis, general skills are also required to work with digital technology. This is, however, only the case for the general skills such as *reading, active learning* and *critical thinking*, and it is the case for a technical skill such as *systems analysis*. Disagreement is apparent in the skills table on the right and, for example, *programming* and *systems evaluation* seems more important for technical and engineering professionals. Another technical-focused disagreement seems to be on *science*, which is not

perceived as important among the management group but that perhaps makes sense because they are not always doing technical or engineering work themselves. Another disagreement is more surprising and that is *technology design* which was not selected among technical professionals but more among engineering and managing professionals. This can indicate that the role of digital technologies in work centres more on the process side as opposed to the tools side. For *decision*-making skills, although there was some respondent agreement, it shows a similar result that may have to do with the more 'sophisticated' kind of digital technologies used in the work. *Mathematics* is another disagreement item and seems to be perceived as more important for engineering and managing professionals.

In summary, the main result is that although some common combinations of knowledge and skills were found among all professionals in all levels, differences among professional levels did appear, especially differences that can be traced back to the roles that the professionals fulfil in their professional level with technical work and professional responsibilities. The work practice of *developing construction plans* showed a similar pattern in Table 16.

Table 16.

Skills and knowledge in work practice 2

Case Summaries digital technology knowledge
in work practice 'develop plans' (N=20)

a	**Technical**	**Engineering**	**Managing**	*Total b*
Admin	71%	18%	8%	*10*
clerical	14%	0%	0%	*1*
economics	29%	5%	17%	*5*
sales	14%	0%	17%	*3*
Customerservice	0%	0%	8%	*1*
HR	43%	5%	0%	*4*
Production	57%	5%	0%	*5*
Computers	43%	36%	25%	*14*
EngTech	43%	45%	33%	*17*
design	14%	41%	17%	*12*
Construction	43%	36%	25%	*14*
mechanical	29%	14%	0%	*5*
mathematics	14%	27%	8%	*8*
physics	0%	18%	0%	*4*
geography	0%	5%	0%	*1*
education	14%	0%	8%	*2*
English	29%	14%	0%	*5*
Security	29%	5%	0%	*3*
Law	14%	0%	0%	*1*
telecommunications	14%	5%	0%	*2*
Media	14%	0%	8%	*2*
transportation	14%	0%	0%	*1*
occupational group total	*7*	*22*	*12*	

Case Summaries digital technology skills
in work practice 'develop plans' (N=20)

a	**Technical**	**Engineering**	**Managing**	*Total b*
Reading	29%	36%	25%	*13*
Listening	29%	5%	0%	*3*
Writing	14%	14%	8%	*5*
Speaking	0%	9%	8%	*3*
Maths	29%	18%	8%	*7*
Science	14%	14%	0%	*4*
Thinking	14%	45%	25%	*14*
Learning	14%	41%	8%	*11*
Strategies	14%	14%	17%	*6*
Monitoring	14%	0%	0%	*1*
Perceptiveness	14%	0%	8%	*2*
Coordination	43%	9%	8%	*6*
Service	14%	5%	0%	*2*
ProblemSolving	29%	32%	0%	*9*
OpAnaly	14%	9%	8%	*4*
TechDesign	0%	32%	8%	*8*
Selection	14%	14%	8%	*5*
Installation	14%	5%	0%	*2*
Programming	43%	9%	8%	*6*
QCAnaly	14%	5%	0%	*2*
OpControl	14%	0%	0%	*1*
Maintenance	14%	0%	8%	*2*
Troubleshooting	14%	14%	0%	*4*
Repairing	14%	5%	0%	*2*
SystAnaly	14%	0%	8%	*2*
SystEvalu	14%	5%	0%	*2*
Decision	14%	9%	8%	*4*
TimeMan	43%	5%	0%	*4*
ManFinRes	14%	0%	0%	*1*
ManMatRes	14%	0%	0%	*1*
ManPersRes	14%	0%	0%	*1*
Other	0%	5%	8%	*2*
occupational group total	*7*	*22*	*12*	

a participants that selected the work were used for the multi response table generation in IBM SPSS-25. Calculated as % from the total in the work group (technical,engineering,managing)
b the results may include the whole range of digital technologies as selected in the top 5 work tasks because the survey was building forward on previous selections

Note:
The table demonstrate the required digital skills and knowledge to be a member of the respective core engineering work practice based on the survey results
The percentages (%) are the share of survey respondents that selected the answer option in the respective survey question
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

*The skills and knowledge constructs in the survey were based on the 35 and 33 O*Net categories*
(a.) The participants that selected the work practice were used for the multi response table generation in IBM SPSS-25. Calculated as % from the total in the work group (technical, engineering, management)
(b.) The results may include the complete range of digital technologies as selected in the top 5 work tasks since the survey was building sequential forward on previous survey selections

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

Table 16 shows that a difference of skills and knowledge for working with digital technologies between different professional levels is visible, like in the work practice of preparing project reports. The table also shows a similar result for the disagreement in professional levels for the skills section on the right. Similar to the earlier work practice, technical design is perceived as more important among engineering and managing professionals. This further supports the argument made that the role of digital technologies for these professional groups may focus more on digital technologies perceived as a process in where they need to be changed to be adapted to work. As opposed to the earlier work practice, decision skills are more selected among technical staff. Perhaps the language component of this work practice is more apparent, which is a surprise since the work practice one was concerned with developing a report and one would assume a significant role for language.

6.5.5 Not all professionals master digital technologies.

The survey also revealed that not all engineering professionals are mastering working with digital technologies. This may interfere with their ability to fully *enact* upon the digital technologies and to use them as intended by the developer so that they can be translated into the core engineering work practice. Namely, Table 17 illustrates that about 47% and 42% of the respondents in both core practices selected that they had not mastered working with digital technologies in their work. This mastery of working with digital technologies is not addressing a possible skills-mismatch of professionals in relation to their work, but this question was addressing the professionals' perspective towards working with digital technology. The notion of a lack of mastery in working with digital technologies could indicate some kind of position and perception of professional responsibility and agency in connection to the digital technology *actors* in the practice and could put their answers into perspective. Surprisingly is that both engineering professionals in South Africa and the UAE appeared confident about their mastery while this was certainly not the case for those in Australia. Perhaps connected to the notion that this latter group selected less explicitly for sophisticated digital technologies and about 75% opted for the answer of 'other' digital technology use in their work may explain this variance. Also, about 60% of the engineering professionals in South Africa opted for mobile devices, CAD and BIM while 50% in the UAE for CAD and BIM and no selections for mobile devices and apps.

Table 17.

Digital mastery of survey respondents

DIGITAL TECHNOLOGY MASTERY OF MEDIUM TO HIGHER SKILLED CONSTRUCTION ENGINEERING PROFESSIONALS IN TWO CORE ENGINEERING WORK PRACTICES

		Total			Australia			South Africa				United Arab Emirates				
Digital technology Mastery		*Total*	*Technical*	*Engineering*	*Managing*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*
Work practice 1	yes	52.8%	63.3%	54.0%	38.5%	26.1%	37.5%	29.0%	75.0%	75.0%	46.7%	66.0%	55.6%	85.7%	0.0%	57.1%
(a.)	no	47.2%	36.7%	46.0%	61.5%	73.9%	62.5%	71.0%	25.0%	25.0%	53.3%	34.0%	44.4%	14.3%	100.0%	42.9%
	cases	*28*	*6*	*14*	*8*	*8*	*2*	*10*	*3*	*5*	*6*	*14*	*3*	*2*	*1*	*6*
Work practice 2	yes	57.8%	72.2%	52.5%	56.0%	30.0%		30.0%	71.4%	75.0%	46.2%	66.0%	75.0%		66.7%	68.8%
(b.)	no	42.2%	27.8%	47.5%	44.0%	70.0%		70.0%	28.6%	25.0%	53.8%	34.0%	25.0%		33.3%	31.3%
	cases	*20*	*5*	*10*	*5*	*5*		*5*	*4*	*5*	*4*	*13*	*1*		*1*	*2*

Note:

The table demonstrates the digital technology mastery for both core engineering work practices
The counts are the survey respondents that selected the answer options in the respective survey questions.
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

(a.) 28 valid cases, Baseline for % calculation are cases

(b.) 20 valid cases.

(c.) The mastery was gathered by posing the question: I master working with this technology (yes/no)
Only the previously selected digital technologies appeared in the respective survey question which is argued to be explicit to the work practice of the respondent

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

For the reason that variances are important in this thesis, the table above addresses the mastery of the respondents aggregated into their professional groups. By counting the selections of *yes* and *no* mastery, the analyse developed an indication about the perceived proficiency to work with digital technologies and can also be understood as someones position towards digital technology use and at the same time their professional ability to work with digital technologies

Table 18.

Case variances digital mastery in survey

CASE SUMMARIES FOR DIGITAL TECHNOLOGY MASTERY (YES/NO) FOR PROFESSIONAL GROUPS

Digital Technology	Mastery yes/No	Professional group	Digitech mastery of respondents		
Total	***N***				***15***
BIM (Building Information Machine Modelling/in the cloud)	No	Engineering	1	EPS2	No
			2	EPS4	No
			3	EPS8	No
			4	EPS15	No
			Total N		4
		Managing	1	EPS3	No
			2	EPS17	No
			3	EPS19	No
			4	EPS20	No
			Total N		4
		Technical	1	EPS7	No
			Total N		1
		Total	N		9
	Yes	Engineering	1	EPS6	Yes
			2	EP7	Yes
			Total N		2
		Total	N		2
Total	***N***				***11***
Computer Aided Design software (CAD)	Yes	Engineering	1	EPS2	Yes
			2	EPS18	Yes
			Total N		2
		Technical	1	EPS7	Yes
			Total N		1
		Total	N		3
	No	Managing	1	EPS3	No
			Total N		1
		Engineering	1	EPS4	No
			2	EP6	No
			3	EPS8	No
			4	EP7	No
			Total N		4
		Technical	1	EPS24	No
			Total N		1
		Total	N		6
Total	***N***				***9***

Note:

The table demonstrates two examples of digital technology mastery for the work practice 1

The counts are the survey respondents that selected the answer options in the respective survey questions
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel

(a.) 30 valid cases, Baseline for % calculation are cases
(b.) Only the previously selected digital technologies appeared in the respective survey question which is argued to be explicit to the

work practice of the respondent

(c.) The mastery was gathered by posing the question: I master working with this technology (yes/no)

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

Since variances are important in this thesis, Table 18 addresses the mastery of the respondents aggregated into their professional groups. By counting the selections of *yes* and *no* mastery, the analysis developed an indication of the perceived proficiency to work with digital technologies and can also be understood as someone's position towards digital technology use and at the same time their professional ability to work with digital technologies. The table above shows that for BIM as an example, 9 out of 11 professionals have not mastered working with BIM. This technology is often associated with more 'sophisticated' digital technologies and is used often in this work practice among engineering and managing professionals as was shown before. Furthermore, for IOT, CAD,the table shows that about three quarter of the respondents have not mastered working with them. However, this particular category of digital technology has been around, at least in the industry, for a much longer time than, for example, BIM. The mastery of Mobile devices and apps surprisingly showed that one-third of respondents have not mastered working with them across all profesisonal levels. , while these technologies are part of everyday life in most social contexts.

In summary, the main finding here is that *not* all engineering professionals, across different professional levels, have mastered working with digital technologies. This may interfere with their ability to use the digital technologies to their full potential as intended by their developers. It may thus affect the notion of their shared responsibility and *enactment* of their practice when digital technologies are a part of it. The main finding that can be derived from the results discussed in this section is that the professional knowledge base is diverse in structure because it both reflects a multi-disciplinary nature and a dimensional nature where both practice and theory are important. This section has thus shown the specific knowledge and skill base required for these professionals to be a member of their core work practices. The next section explores the learning mode that is best associated to deliver the individual knowledge and skill base to be a member of the two selected engineering work practices.

6.6 Professional learning from experience, professionals, and academic schooling

The survey showed that learning through and from others' work experience is reported as the dominant mode of learning for work in the core engineering work practices. These practices were highly digitalised. Experience-based learning was, both in a digital technology-rich context and when explicitly referring to working with digital technologies, popular. This is because of the data coming from three sections in the survey.

(1) mechanisms, such as *using trial and error* (22% and 19%), *learning from a colleague* (16% and 16%) and *using intuition/gut feeling (*15% and 13%) were selected in the survey. This can be understood as being more on the learning by participation side. Mechanisms such as *while studying for my qualification* (24% and 21%), *during work-based training* (8% and 15%) and *reading books* (6% and 8%), which can be understood as learning as an acquisition mechanism, were also selected but with much more distance after the most apparent selection.

(2) For learning knowledge, results were similar, except that the acquisition mechanism *while studying for my qualification* was selected much more often with 39% and 45%. Although the questions about learning were not explicitly directly linked to working with digital technologies, the question was posed underneath each selected engineering practice and both showed in part A of this overview a significant share (above 70 and 80%) of digital technology use in work.

(3) Learning to put digital technologies into practice happens through practice because two-thirds of selections were made for while working in both practices compared to 15% in school, and 8% during training. The responses were similar across the countries but different across professional levels. Namely, 67% of technical staff in South Africa in both work practices selected that they had learnt to work with digital technologies in school as opposed to 0% of technical staff in the UAE. The small difference between technical and engineering professionals, of which the former had a slight preference for learning in school over while working, may indicate a difference between the different engineering levels and across countries.

The results concerning the dominant ways of learning for the core engineering practices were derived by analysing the questions in the survey about the dominant learning skills and knowledge. Again, due to the loop and merge design of the instrument, questions were explicitly relating to one specific core engineering work practice because the skills and knowledge for that core work practice were selected earlier and came back in this learning question. It was also only referring to the knowledge (or skill) used in their work without referring to any performance indicators as again, the skill-mismatch discussion was not relevant to the current thesis.

6.6.1 Learning skills through work participation and in education.

Learning skills for work happens through both work participation and academic education. This view is supported by the survey results and shown in Table 19.

Table 19.

Dominant learning modes for work skills in work practices

LEARNING SKILLS FOR WORK OF MEDIUM TO HIGHER SKILLED CONSTRUCTION ENGINEERING PROFESSIONALS IN THE CORE ENGINEERING WORK PRACTICES

		Prepare project reports				Develop construction plans			
Learning dimensions		*TOTAL*	*Technical*	*Engineering*	*Managing*	*TOTAL*	*Technical*	*Engineering*	*Managing*
Learn Skills	from a collegue at work	15.6%	19.2%	13.8%	15.1%	16.2%	24.8%	13.3%	7.0%
(a.)	Using trial and error on the job	21.8%	19.2%	28.8%	14.0%	18.9%	22.9%	17.3%	24.0%
	reading books, manuals, magazines	6.2%	9.3%	7.3%	2.2%	7.7%	8.5%	9.7%	2.0%
	while studying for my qualification	24.3%	19.9%	25.8%	25.8%	21.2%	21.6%	23.0%	15.0%
	during work-based training	8.2%	6.6%	7.3%	10.8%	15.0%	2.6%	20.9%	21.0%
	using internet	4.2%	7.9%	3.8%	1.6%	3.6%	3.3%	3.6%	4.0%
	while taking an online course	0.2%	0.7%	0.0%	0.0%	0.2%	0.0%	0.5%	0.0%
	Using intuition/gut feeling	15.4%	14.6%	12.3%	20.4%	13.4%	15.0%	11.2%	14.0%
	other...	4.2%	2.6%	0.8%	10.2%	3.6%	1.3%	0.5%	13.0%
	total	597	151	260	186	**439**	**153**	**196**	**100**
	cases	30	6	15	9	*20*	*5*	*10*	*5*

Note:

The table demonstrates the dominant learning dimensions for both core engineering work practices
The % are based on the counts of the survey respondents that selected the answer options in the respective survey questions.
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
The learning mode constructs were based on the research of Felstead et al. (2005) and further categories added
a. aggregated from all learning mode categories, instances that workers selected this underneath the skills that they selected

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

Firstly, in the table can be seen that the learning modes connected to the skills in the work practices are mostly found in the participation corner of the two paradigms, namely, *using trial and error*, *from a colleague at work* and *using intuition*, whereas only one dominant is found in the acquisition corner of the two paradigms *while studying for my qualification*. The table shows that the work practice of *preparing project reports* variances are relevant to consider since the different blue and red horizontal colours indicate differences across professional groups and therefore Table 20 illustrates these differences.

Table 20.

Dominant learning modes for work skills with variances

LEARNING SKILLS FOR WORK PRACTICE 1 OF MEDIUM TO HIGHER SKILLED CONSTRUCTION ENGINEERING PROFESSIONALS IN THE CORE ENGINEERING WORK PRACTICES BY PROFESSIONAL LEVEL AND COUNTRY

		Total				**Australia**		**South Africa**				**United Arab Emirates**				
Learning dimensions		*Total*	*Technical*	*Engineering*	*Managing*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*
Learn Skills	from a collegue at work	15.6%	19.2%	13.8%	15.1%	9.4%	39.1%	17.8%	28.0%	17.8%	5.9%	16.3%	5.2%	16.7%	13.6%	10.7%
(a.)	Using trial and error on the job	21.8%	19.2%	28.8%	14.0%	34.2%	6.5%	26.4%	12.9%	16.8%	16.1%	15.4%	29.3%	42.9%	18.2%	32.0%
	reading books, manuals, magazines	6.2%	9.3%	7.3%	2.2%	1.7%	0.0%	1.2%	2.2%	14.9%	3.4%	6.7%	20.7%	4.8%	0.0%	11.5%
	while studying for my qualification	24.3%	19.9%	25.8%	25.8%	31.6%	26.1%	30.1%	25.8%	24.8%	28.0%	26.3%	10.3%	11.9%	13.6%	11.5%
	during work-based training	8.2%	6.6%	7.3%	10.8%	6.0%	13.0%	8.0%	4.3%	9.9%	11.0%	8.7%	10.3%	4.8%	4.5%	7.4%
	using internet	4.2%	7.9%	3.8%	1.6%	0.9%	0.0%	0.6%	3.2%	6.9%	2.5%	4.2%	15.5%	4.8%	0.0%	9.0%
	while taking an online course	0.2%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	0.0%	0.0%	0.8%
	Using intuition/gut feeling	15.4%	14.6%	12.3%	20.4%	14.5%	15.2%	14.7%	23.7%	8.9%	16.9%	16.3%	0.0%	14.3%	50.0%	13.9%
	other...	4.2%	2.6%	0.8%	10.2%	1.7%	0.0%	1.2%	0.0%	0.0%	16.1%	6.1%	6.9%	0.0%	0.0%	3.3%
	cases	30	6	15	9	8	2	10	3	5	6	14	3	2	1	6

Note:

The table demonstrates the dominant learning dimensions for core engineering work practice 1
The % are based on the counts of the survey respondents that selected the answer options in the respective survey questions.
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
The learning mode constructs were based on the research of Felstead et al. (2005) and further categories added
a. aggregated from all learning mode categories, instances that workers selected this underneath the skills that they selected

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

What the table illustrates is that some of the variances across professional levels and countries are visible but the perspectives for *learning in academic education* and by *using trial and error* seem similar. For example, managing professionals in South Africa do not seem to value learning from a colleague at work while managing professionals in both Australia and the UAE do seem to value learning from colleagues. Also, *reading books and manuals* is more valued among engineering professionals in South Africa and technical professionals in the UAE, which is similar in the second core work practice of *developing construction plans*. What this means is that learning skills for work is not the same for all professionals across professional levels and countries. It is also not similar for all aspects across different engineering work practices. The implication of this for professional learning is that *one size does not fit all* is applicable and both professional level and context are extremely important in any discussion regarding the design and development of education for engineering practice.

6.6.2 Individual knowledge predominantly through academic education.

The survey showed that learning for work knowledge happens predominantly through academic education but at the same time, participatory learning modes were perceived as important among some respondents. The same process in the analysis was followed for the dominant learning modes connected to work knowledge. The results for the work practices are shown in Table 21.

Table 21.

Learning knowledge for work in work practices

LEARNING KNOWLEDGE FOR WORK OF MEDIUM TO HIGHER SKILLED CONSTRUCTION ENGINEERING PROFESSIONALS IN THE CORE ENGINEERING WORK PRACTICES

		Prepare project reports				Develop construction plans			
Learning dimensions		*TOTAL*	*Technical*	*Engineering*	*Managing*	*TOTAL*	*Technical*	*Engineering*	*Managing*
Learn Knowledge	from a collegue at work	15.5%	20.0%	12.7%	15.7%	15.4%	26.2%	11.5%	6.0%
(a.)	Using trial and error on the job	17.6%	8.4%	19.6%	24.1%	10.9%	10.7%	12.4%	8.0%
	reading books, manuals, magazines	7.1%	8.4%	8.9%	2.4%	4.9%	1.2%	8.8%	2.0%
	while studying for my qualification	39.3%	44.2%	40.5%	31.3%	44.5%	54.8%	40.7%	36.0%
	during work-based training	11.0%	7.4%	8.9%	19.3%	17.0%	1.2%	16.8%	44.0%
	using internet	6.0%	8.4%	7.0%	1.2%	3.6%	2.4%	5.3%	2.0%
	while taking an online course	0.3%	0.0%	0.0%	1.2%	0.4%	0.0%	0.0%	2.0%
	Using intuition/gut feeling	3.3%	3.2%	2.5%	4.8%	3.2%	3.6%	4.4%	0.0%
	other…	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	total	336	95	158	83	***247***	***84***	***113***	***50***
	cases	30	6	15	9	***20***	***5***	***10***	***5***

Note:

The table demonstrates the dominant learning dimensions for both core engineering work practices
The % are based on the counts of the survey respondents that selected the answer options in the respective survey questions.
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
The learning mode constructs were based on the research of Felstead et al. (2005) and further categories added
a. aggregated from all learning mode categories, instances that workers selected this underneath the knowledge that they selected

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The table shows, for example, that the learning mode of *while studying in school* was selected among 39% of respondents in the work practice of *preparing reports* and the distance to the next learning mode is significantly more than among learning for skills. This means that more responder agreement is reached for learning knowledge for work. This result is not surprising, considering the expectation that schooling is required to learn the formal knowledge base for work while learning skills for work is more associated with participating in work. The table shows that inconsistencies derived from the differences between the red and blue colouring are significantly less than in the skills section.

Table 22.

Learning knowledge for work -variances work practice 1

LEARNING KNOWLEDGE FOR WORK PRACTICE 1 OF MEDIUM TO HIGHER SKILLED CONSTRUCTION ENGINEERING PROFESSIONALS BY PROFESSIONAL LEVEL AND COUNTRY

		Total	Australia					South Africa				United Arab Emirates				
Learning dimensions		*Total*	*Technical*	*Engineering*	*Managing*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*
Learn Knowledge	from a collegue at work	15.5%	20.0%	12.7%	15.7%	15.4%	32.0%	20.0%	25.0%	10.9%	6.3%	14.8%	12.0%	10.3%	20.0%	12.5%
(a.)	Using trial and error on the job	17.6%	8.4%	19.6%	24.1%	21.5%	32.0%	24.4%	9.4%	10.9%	16.7%	11.9%	8.0%	34.5%	40.0%	25.0%
	reading books, manuals, magazines	7.1%	8.4%	8.9%	2.4%	4.6%	0.0%	3.3%	1.6%	12.5%	4.2%	6.3%	28.0%	10.3%	0.0%	15.6%
	while studying for my qualification	39.3%	44.2%	40.5%	31.3%	43.1%	16.0%	35.6%	56.3%	39.1%	43.8%	46.6%	24.0%	37.9%	10.0%	28.1%
	during work-based training	11.0%	7.4%	8.9%	19.3%	9.2%	20.0%	12.2%	1.6%	12.5%	22.9%	11.4%	0.0%	0.0%	0.0%	0.0%
	using internet	6.0%	8.4%	7.0%	1.2%	6.2%	0.0%	4.4%	1.6%	9.4%	2.1%	4.5%	28.0%	3.4%	0.0%	12.5%
	while taking an online course	0.3%	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.6%	0.0%	0.0%	0.0%	0.0%
	Using intuition/gut feeling	3.3%	3.2%	2.5%	4.8%	0.0%	0.0%	0.0%	4.7%	4.7%	2.1%	4.0%	0.0%	3.4%	30.0%	6.3%
	other...	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	cases	30	6	15	9	8	2	10	3	5	6	14	3	2	1	6

Note:

The table demonstrates the dominant learning dimensions for core engineering work practice 1
The % are based on the counts of the survey respondents that selected the answer options in the respective survey questions.
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
The learning mode constructs were based on the research of Felstead et al. (2005) and further categories added
a. aggregated from all learning mode categories, instances that workers selected this underneath the knowledge that they selected

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

Some variances are recognizable in Table 22 such as the variance of learning *while reading books and manuals* for technical and engineering professionals in the UAE as compared to the engineering professionals in Australia and the technical professionals in South Africa. What this means is that learning knowledge for work is like learning skills for work and is not the same for all professionals. Learning knowledge is also not the same across different engineering core practices. A different picture emerges when looking at the second work practice of *developing construction plans*. This knowledge diversity across diverse levels supports the previous point that for professional learning, one size does not fit all must be applied and contextual considerations are relevant.

6.6.3 Digital practice happens through practice.

The survey revealed that learning to work with digital technologies happens at work. Similar to the earlier sections on learning skills and knowledge for work, this section was explicitly building forward on earlier selections of digital technologies in the specific core engineering work practice. The difference was, however, that no specific learning modes were used but only the broad categories of *while working, during training, in school* and *other*. The focus shifts now to see whether a specific *location* of learning would be most apparent in learning to work with digital technologies in the practice of preparing reports. This is shown in Table 23.

Table 23.

Learning to work with digital technologies

LEARNING PLACE OF MEDIUM TO HIGHER SKILLED CONSTRUCTION ENGINEERING PROFESSIONALS IN THE CORE ENGINEERING WORK PRACTICES FOR DIGITAL

		Prepare project reports (b.)				Develop construction plans			
Learning dimensions		*TOTAL*	*Technical*	*Engineering*	*Managing*	*TOTAL*	*Technical*	*Engineering*	*Managing*
Learning place digital technology	In school	14.6%	12.1%	34.8%	7.4%	14.5%	50.0%	5.0%	4.0%
(a.)	while working	56.7%	65.4%	34.8%	40.7%	62.7%	27.8%	85.0%	52.0%
	during training	8.3%	6.5%	4.3%	18.5%	8.4%	0.0%	5.0%	20.0%
	other	20.4%	15.9%	26.1%	33.3%	14.5%	22.2%	5.0%	24.0%
	total	157	107	23	27	***83***	***18***	***40***	***25***
	cases	29	6	15	8	***20***	***5***	***10***	***5***

Note:
The table demonstrates the dominant digital learning dimensions for both core engineering work practices
The % are based on the counts of the survey respondents that selected the answer options in the respective survey questions.
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
The learning place constructs were based on the research of Felstead et al. (2005) and further categories added
a. aggregated from all learning mode categories, Instances that workers selected this underneath the knowledge that they selected
(b.) 29 valid cases, Baseline for % calculation is total
Source data: 2018-2019 STWL-survey (de Munnik, 2020)

What the table reveals is that the preferred learning mode for digital technologies among engineering professionals is clearly *while working* because it was selected by 57% and 63% of respondents and to a significantly less extent during training or school. Considering variances among professionals which is illustrated in Table 24, technical staff are slightly more positive about learning in school for the work practice of *developing plans* but not for the practice of *preparing project reports*. Also, technical and managing professionals in SA prefer more to learn in school and through other methods – which were not further specified in the survey. If we complement the above with the learning mode for skills and knowledge in the specific work practices, where learning modes related to learning at work were selected and consider the high selections of digital technologies in both, this further supports the perception of the workplace as an important location for learning.

Table 24.

learning place to work with digital technology in work practice 1

LEARNING PLACE OF MEDIUM TO HIGHER SKILLED CONSTRUCTION ENGINEERING PROFESSIONALS IN THE CORE ENGINEERING WORK PRACTICE 1 FOR WORKING WITH DIGITAL TECHNOLOGY

		Total	Australia					South Africa				United Arab Emirates				
Learning dimensions		*Total*	*Technical*	*Engineering*	*Managing*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*	*Technical*	*Engineering*	*Managing*	*Total*
Learning place digital technology	In school	14.6%	12.1%	34.8%	7.4%	10.0%	0.0%	7.7%	66.7%	0.0%	6.7%	19.1%	0.0%	0.0%	33.3%	4.8%
(a.)	while working	56.7%	65.4%	34.8%	40.7%	86.7%	77.8%	84.6%	16.7%	90.0%	13.3%	46.8%	54.5%	100.0%	66.7%	71.4%
	during training	8.3%	6.5%	4.3%	18.5%	0.0%	0.0%	0.0%	0.0%	5.0%	33.3%	12.8%	9.1%	0.0%	0.0%	4.8%
	other	20.4%	15.9%	26.1%	33.3%	3.3%	22.2%	7.7%	16.7%	5.0%	46.7%	21.3%	36.4%	0.0%	0.0%	19.0%
	total	157	107	23	27	30	9	39	12	20	15	47	11	7	3	21
	cases	29	6	15	8	8	2	10	3	5	5	13	3	2	1	6

Note:
The table demonstrates the dominant digital learning dimensions for core engineering work practice 1
The % are based on the counts of the survey respondents that selected the answer options in the respective survey questions.
The table is based on the survey results that were first generated with IBM SPSS-25 and further amended in MS Excel
The learning place constructs were based on the research of Felstead et al. (2005) and further categories added
Aggregated from all learning mode categories, instances that workers selected this underneath the knowledge that they selected

(a.) 29 valid cases, Baseline for % calculation is total

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The main result that can be derived from this section is that professional learning is specific to individuals since multiple variations within groups and across groups were found. Although knowledge learning is more associated with academic schooling than skills learning, participatory work practice modes of learning are highly valued. The participatory modes are especially important for learning skills. Therefore, I believe based on the previous discussion of results that learning to put digital technologies into practice happens through participating in work practice, but the academic knowledge base remains important to consider.

6.7 Chapter summary

In this chapter, the results of the *STWL-survey* that were found were divided into the three areas of concern in the empirical work: namely, work, skills and learning. The main insight which can be derived from this Chapter is that '*one size does not fit all'* applies to professional practice and learning of the participating engineering professionals in this study since the digital work technologies were different for each professional and context, as were skills, knowledge and learning mechanism.

In sum, the survey results have shown that the two selected core engineering work practices are highly digitalized and possibly digitally innovated which means that the practices have changed in the nature of the practice itself. Furthermore, the chapter has shown that strong associations

between digital technologies, practice and professionals exist. Thus, this supports a view that a core engineering work practice is relational and relations between digital technology and professionals exist. At the same time, this chapter has shown through the exploration that variances existed, across countries and across professional levels such as for instance that higher engineering levels experienced more advancement of work as opposed to lower engineering levels and lower technical professionals in some locations preferred learning in school as opposed learning in work. This means that different understandings about the intensity and impact of digital technology among engineering professionals exist which does not appear when taking averages or using standard statistical procedures.

Although pre-existing assumptions about associations between practice, professional and digital technologies were confirmed, the survey results did not reveal any further specifics about the nature of these relations and the next chapter shows more specifics about the nature of these variances, relations, and insights for implications for understandings about professional engineering practice and learning.

CHAPTER 7 -

ONE SIZE DOES NOT FIT ALL - CASE STUDY INTERVIEW RESULTS

7.1 Introduction

This chapter presents the interview results that were derived from the qualitative part of the empirical work in this thesis which was informed by sociomaterial sensibilities for the research design and the analysis. The previous chapter showed, based on the survey results of this group of engineering professionals, that the notion of *one size does not fit all* is relevant when considering the professionality and learning of this specific group of engineering professionals. This chapter elaborates on that account by showing that each *builder is rebuilding or rebuilding their core work practice in a sociomaterial way*. This chapter is exemplifying the engineering professionals' perceptions by following sociomaterial sensibilities when presenting the interview results. The adoption of sociomaterial sensibilities had consequences for the language use and how the interview results were described in this chapter. The normal use of *discussion* of interview results may become confusing and has therefore been removed from the chapter's vocabulary. Instead, description, illustration and depiction are used. Also, I have tried to explain the case stories with *actors* and actions by using neutral and sociomaterial terminology. I do this by describing a relation between *actors* without interpreting and discussing but only by trying to describe the story based on the interview transcripts. This could be perceived as a sociomaterial sensibility (see 4.2) and the reader must be aware that the objective of this chapter is therefore not to interpret results but rather explores and describes them. The role of the next chapter is to make a move to more focused insights based on the descriptions of results in Chapters 6 and 7 supplemented by the explorations following from the other chapters.

This chapter presents that the main results that were derived from the engineering professionals' perceptions were in the interviews was that relations between engineering professionals and digital technologies were predominantly found in the automating of reasoning work activities in work practices and differences appeared between engineering professional with more complicated roles, managing responsibilities and technical managing responsibilities. This chapter starts with elaborating on the five principles of practice framework, presents four case example stories which approach is common in sociomaterial research (Mulcahy, 2012; Zukas & Malcolm, 2019), continues with a summary and concludes with common understandings resulting from the empirical work in where the survey results are also briefly considered. When interview case

summaries are presented, the professional attributes are not further specified, or countries identified. This is because professional information about the interview informants is revealed that with referring to a country would have resulted in the question of my ethical considerations towards keeping their identities private. This does not mean that I have not considered these personal attributes and country attributes when analysing the data, but I decided to refer only to the notion of well- and medium-developed work context based on the degree of innovation in that work location.

7.2 The 5 principles of the practice-theory and ANT as an approach

The previous chapter explored the study through a quantitative approach and this chapter continues the exploration through a qualitative approach. The previous chapter discussed the results by using professional cases to exemplify similarities and differences in country contexts. This chapter shows the results from the qualitative part of the study, whereby sociomaterial sensibilities are the theoretical framework and tool of analysis. In this framework, the focus for the results shown in this chapter is the two earlier selected engineering work practices of preparing project reports and developing construction plans. However, since this thesis is answering a social question about humans, the viewpoint starts with the engineering professionals. The engineering professionals are at the same time the human *actors* that constitute the practice. Digital technologies also constitute the practice but are then understood as non-human *actors*. However, this use of the notion of non-human *actors* does not mean that a pre-existing power difference between human and non-human *actors* is advocated or foregrounded in this chapter. Both receive the same possible agency upfront and may *enact* each other in practice. To restate the main point from the earlier discussion in chapter 4, agency here is seen from the generalised symmetry concept which is argued for in sociomaterial theories such as *Actor* Network Theory and has nothing to do with arguing about whether or not humans or non-humans are different. It has also nothing to do with arguing of they could be regarded as a deliberate entity but rather removes the upfront allocation of power from the discussion and treat them with the same approach as humans and the same language.

> The five principles of practice outlined above – practice as knowledgeable action, as embodied and materially mediated doings and sayings, as relational, as evolved in historical and social contexts and power relations, and as emergent – challenge us to theorise learning, practice and change differently. Practice, learning and change are brought into a new and more complex relationship among the elements, each raising critical questions of how learning might be understood as patterned, embodied, networked and emergent (Hager et al., 2012, p. 8).

The results in the qualitative data section that followed on the surveys were based on the sequential design of the study and were acting partially sequential in the analysis. The interview results were constructed by (1) using content analysis, following the conceptual organization of the five principles of practice (Hager et al., 2012, p. 3) and thereby following Reich et al. (2015), specifically in engineering; and (2) using the visual representational power of *Actor*-Network Theory to make the relations between the different constitutes in the practice and connections to learning visible. A data-driven analysis using a contrasting approach based on professional levels and their work context produced interesting results underneath the five principles of practice. NVIVO 12, Microsoft Excel and IBM SPSS-25 were used to develop the analysis and visual representations in this chapter. First, the survey results were confirmed and validated in the sense that all interview informants confirmed the correct selection of work in the survey. One electrical engineer indicated that different work was taken on since completion of the survey but then the interview focused on the work practice that was positively confirmed. Another professional, an assistant engineer, expressed that some of the work tasks in the survey were not closely related to the actual personal practice but said that the survey selections were made for the ones that applied to his work. The other interviewees confirmed without hesitation the selection of their work practices in the survey completely.

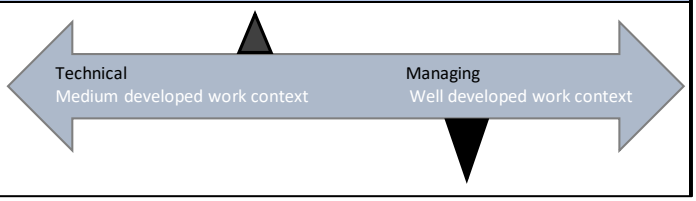
Two case stories to exemplify the interview results with one from each work practice are described and followed by a discussion by following the five principles of the practice-theory. Thereafter, two other case stories with one from each engineering work practice are described by following the five principles of practice but complemented by the visual representational power of the ANT to trace the relationships between the human and non-human *actor*. The selection of the four cases as illustration of the interview results may be understood as a network boundary demarcation because I made selections in what was described and where to end the network. Ideally, in the perfect ANT world, one would go on to describe the network without boundaries and ends but following common practical approaches from those researchers who used ANT in any of its forms (ANT and post ANT),boundary decisions were made.

7.3 Engineering professional (EP6) that sociomaterial *rebuilds* work practice 1

The first case that is presented is engineering professional 6 and shows a male engineer working in a well-developed work context with predominantly engineering responsibilities in his discipline of mechanical engineering.

Figure 20.

Description, context and role of engineering professional case (ep6)

Empirical case EP6	**Engineering level**
EP6 is a male and full engineering qualified (graduate level) mechanical engineer working in a larger engineering construction firm, based in a well developed work context and operating in various countries across the globe.	

The practice of preparing reports and document project activities and data is for this operational professional perceived in two ways. Where the one can be a technical report with technical specifications about a mechanical feature or process, the other can be a design-specific report in where the mechanical component is part of a larger project and the aim is providing a quality report as the quote below highlights:

> Usually if it is a technical specification that will be based on calculations so that a lot of the information component where we assess options and then provide commentary on why we selected what we've selected. But the reports are often based on site information from a greater site in a review installation, take photos to review as installed equipment they often that we will be looking at existing data and then commenting on that. But often that has left calculations and more review of photos and get back photos and plans two that are slightly different but that the sort of thing we often do. (EP6)

The professional sees this practice as a goal since in the end, he needs to align with deliverables in both forms of a report and that is his goal. Activities in this practice are focused on information components in which calculations taking up a fair share and assessing options is a key part for the preparation of the data what goes into the report. Initially, a [construction] site visit is done where photos are taken and reviewed. It then requires another site visit before a report is compiled. The practice is a fair share of this professional's work as he spends, on average, two of his weekdays on this practice, depending on the stage of the project.

The principles of the practice applied to this engineering professional are described next and each time, the five principles are the guidelines which are used.

The first principle of the practice, "practice is more than the simple application of theoretical knowledge or a simple product of learning" (Hager et al., 2012, p. 3), was used to show a move beyond knowledge residing in the individual professional. This engineering professional learnt by doing the work practice. Since his practical knowledge of engineering and construction was what he needed to apply in a real-world context when he started working, the practical kind of job knowledge was thus learnt by *doing* in practice. Although he selected in his survey that he learnt 24% of his knowledge for work during studying for a qualification at school, the elaborated interview account showed that he learnt his practice by accumulating practical day-to-day knowledge at work. He argued that although he learnt a lot of the theoretical base of his work practice in school, this was not common for most engineering professionals. He indicated that he still used daily the theoretical part of what he learnt in school. He argued that the day to day practical work was not what he had learnt in school but only the theoretical part which is illustrated in the quote below:

> I would say probably. A 60 percent colleagues and then 20. So, I would say, the majority of it ,and that's not true for all engineering professionals but the majority of the practices that I do on a day to day are actually part of a university course. [interviewer confirms if thus a lot of his practice was learnt in University] Yeah I would say the theoretical side of the practice. that day to day maybe not so much, so all of the theory but maybe none of the practical. (EP6)

This engineering professional had allocated in his survey, similar importance to using *trial and error* on the job and learning *while studying for a qualification* with both 22%. The professional selected three knowledge areas required for this practice, ranging from two disciplinary knowledge areas to one social knowledge which he altogether learnt by books, from colleagues and by using trial and error. He explained during the interview that he learnt his administration and management for 100% on the job from his colleagues. The professional selected only a few work-skills, of which all four were general skills required to execute the daily work practice. These skills were either learnt in school or during work-based training of which he selected only 8% in the survey. He elaborated in the interview that work-based training included for 60% learning from colleagues, 20% internal and supplier-led which thus appeared as more dominant learning mode as opposed to which appeared in his survey results. Two of the five skills and knowledge areas that this professional selected in the survey to work with digital technologies specifically were different as opposed to the skills and knowledge package for the practice, namely, installation and troubleshooting. The professional

explained during the interview that general skills such as critical thinking are easier to implement to work with technologies, but other things could develop more scope and potential to work with digital technologies. For instance, he argued that for his work practice, the ability to programme would make things much easier and save time since he could adapt the digital technologies more specifically to what he needed. For specific skills such as troubleshooting and installation, he referred to the increase of time and the requirement to relearn how to do things when working with digital technologies for the first time. The comments below illustrate that view:

> Just because in my experience [of being] that some of the processes have required re-learning how to do things. (EP6)

> I think that in fact, in a strange way.... the skill level of a general technology still has [is.] But the technical skill level has to remain the same. (EP6)

> You need the same engineering skills you just need less administration. (EP6)

He also stated that software specifically has led to fundamental knowledge in the sense that it automated specific manual calculations:

> So, it is actually that what I was thinking, was that the software I was talking about we actually did those calculations by hand. And then, see that led to fundamental knowledges, software has supplement that by using software. (EP6)

The second principle of the practice theory "Understanding practice as a sociomaterial phenomenon, involving human and non-human *actors* in space and time" (Hager et al., 2012, p. 3), was considered next to trace the different participating members in the practice. The practice is sociomaterial for this professional because both human and non-human *actors* constituted the practice. The human *actors* that were involved were both clients, who gave the directions for their needs and requirements, and a smaller engineering team of two to three professionals with a leading entity. When the practice concerned the technical report, a team with only mechanical engineering professionals was the constitution and where the practice was a design report, different engineering disciplines such as electrical and hydraulic were included as members of the practice. The only non-human *actor* that was selected in the survey was CAD which was used for 80%. But Then in the interview, it appeared that a variety of different technologies were involved in the practice, such as MS Excel, MS Power BI, and calculation and simulation software. Regarding the last, the professional

indicated to run a worst-case scenario as a baseline for his design of which he referred to as running a realistic worst-case scenario. The comments below illustrate this:

> So, I said typically we use uhm, like software packages see the do calculations and then really see products like Microsoft Excel or Word or Power BI to provide answers or for quality report. (Ep6)

> It's like a sort of very high-level simulation software situation? Usually ideally. It's worst case but then the worst case is just a baseline for the design. It's not a ...it's not an extreme worst case. (Ep6)

The third principle of the practice theory is, "Practice is embodied and relational" (Hager et al., 2012, p. 3), was used to develop insights into the existence and nature of relations of this engineer's practice since the principle allowed to highlight the different *actors* and their power to shape the practice. The practice was understood to be relational in the sense that the practice was formed with both human and non-human *actors*. For example, the relations with the clients who gave clear directions for what they required was significant for the shaping of work this professional's practice. The professional also saw an enhancement of human skills by digital technology happening and at the same time thought that the engineering skills that were required for the practice were staying the same. Altogether, this shows the relations between this professional human-*actor* and both other human and non-human *actors* and connections to the practice, which is illustrated with the quote below:

> Usually the technical parts are components of projects or reports from their own, that will be the client. A client will ask us to do a report [interviewer confirms]if those are some of the technical ones often you know the building the size and then we have very clear guidelines for observation type records. Often it will be: we have a problem, come find out what the problem is. (EP6)

The fourth principle of the practice theory, " practices are neither stable, homogeneous nor ahistorical" (Hager et al., 2012, p. 4), was used to show the complexity of the work practice of this professional by focusing on context and change. The work practice for this professional was mostly bound to the local office environment, but he performed regular site visits to the construction site. Thus, the practice took place directly on the construction site and in his office environment. The practice was shaped by both reverting to previous practices and also by gathering new data first. Thereby the historical contextual nature of the practice became visible as is shown in the quote below:

> Usually this would be in the office but the sub practice of going and doing a site review is up alongside the site. I would say, probably on a constant basis. I think we would typically revert back to previous problems but mostly it's gathering data first. So, I would just find as much information as possible about problems and other things around the problem. (EP6)

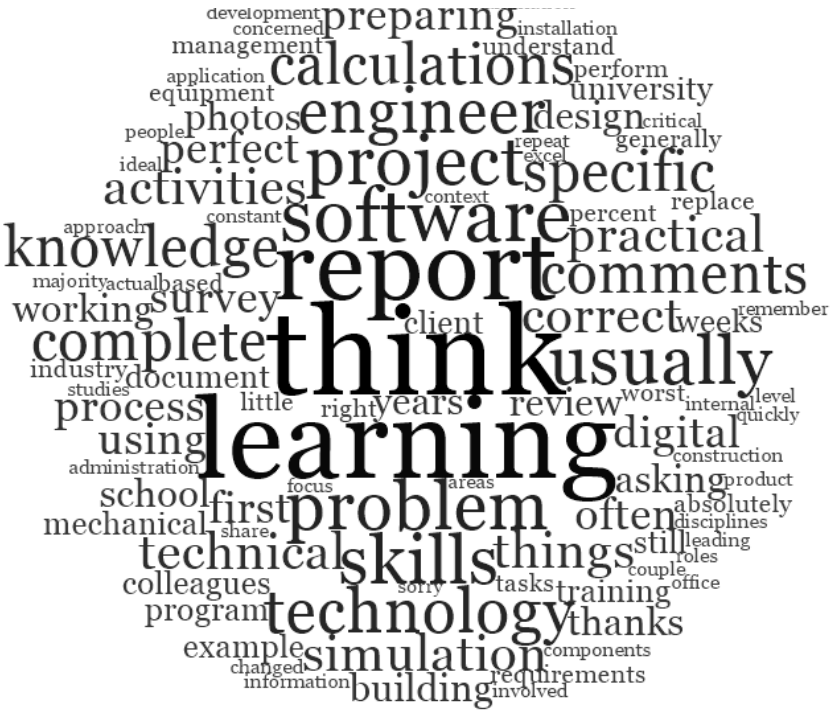
The fifth principle of the practice theory," practices are emergent, in the sense that the ways in which they change and evolve are not fully specifiable in advance" (Hager et al., 2012, p. 5), was used to explore the way in which the practice has changed. The work itself had not changed for this professional but the completion mode transformed into digital format. In that sense, the work became automated when it first departed from a manual variant. The reduction of effort and time were essential benefits in this process. The work in the professionals 'company had transformed into streamlined processes which reduced professional effort and time by allocating tools that made the practice easier. Such as direct annotations on photos that were captured for the purpose of a report during a construction site visit. The final report was made instantly and on the go. The interview comments below illustrate this:

> But I guess uhm the software we're using is quit. I don't say cutting edge, but I guess probably one of the more sophisticated software's where there are more simple software's and they've been used in the industry for At least 10 years. But.... absolutely! the calculations that we're doing we're doing could be done by hand. It would just take weeks instead of hours. (EP6)

> In my company has been a strong push to streamline some of the processes that we do for technical and reporting and an internal program has been developed to take photos, make comments and generate the report while you are on site. Basically, that ask that you take photos and make comments on and then it generates the PDF report. It's a little bit glitchy but it saves time. [interviewer poses that this activity was possible before with a pen and paper] You could...but you had to go back and type it up and add photos and things like that. Now in theory. You could do all your comments while you are on site and then by the time you get back to the office you will have a report ready to issue. (EP6)

Figure 21.

Word cloud interview with case EP6



The word cloud which was generated from the interview transcript depicted in Figure 21 shows that different terms appear important for this engineering professional's work practice of *preparing project reports*. They range from words which indicate the use of specific digital technologies, such as *simulation*, to words indicating learning modes such as *university* and *practical*. Although the word cloud is a powerful visual instrument to make the content of most reoccurring words in the interview visible, it does not show the exact context of the words. That requires a more in-depth view which is done next by using the five principles of practice to summarize this professional's interview results by using a specific sociomaterial vocabulary.

To conclude, departing from this professional's view which was illustrated by describing the case story by following the five principles of practice, the work practice of delivering a technical or quality specification report has changed for this professional. Part of these changes can be attributed to the doing of the non-human digital *actors* in the practice, such as the use of sophisticated digital technologies for reporting that were used in-company. The results of the capabilities of these digital technologies for professional responsibility were that their use has led to a reduction of professional time and effort. The reduction of professional effort and the specific explanations of the activities involved seemed to demonstrate that some steps in the work process changed while the outcome or the delivery remained the same. The digital capabilities constituting the reporting software that this professional referred to may be understood as data capturing and streamlining. These *performing*'s

are more aligned with the automation of a previously manual process but at the same time an indication of innovation because some steps in the work process have changed and refined the work. Another acting of a non-human, digital *actor* in this work practice was found in simulations. The digital simulation was running a realistic worst-case work scenario that informed the design activity in this practice and could be understood as a digital reasoning capability which informed the professional decision making of the human professional. Other non-human *actors* which were involved were physical locations such as the construction site that *enact*ed upon the practice in where the professional took part because they provided specifics and changed the required processes and outcomes. The acting of other human-*actors* in the practice, such as clients, also defined the nature of the practice because they provided the specifications for the required report or, as I argue, a requirements baseline for the outcome of this practice. When it came to the professional acting of this human-*actor* in the practice, the professional argued that he had to relearn how to do things when digital technologies were introduced as members into his work practice but also his general skills appeared useful when working with them. At the same time, he said that his professional engineering skills remained the same when working with digital technology. His learning to be a professional member of this practice appeared to have ranged from a knowledge foundation that was learnt in school and which he still used as a theoretical foundation of his daily work practice but also the learning of his practical job knowledge that he learnt in practice. He demonstrated a strong preference for learning from colleagues as a form of training when he had to learn practical work knowledge.

7.3.1 Summary of case story Ep6.

In sum, the role of digital technologies in the work practice of this human engineering professional can be understood as non-human digital *actors* which are *performing* part of the professional responsibilities of this engineering professional such as those capabilities found in the area of reasoning. When it comes to individual professional responsibilities, time and effort reduction were the main positive consequences for this professional but also streamlined work processes and quality improvement could be derived from the human-digital interactions in this work practice seen from the engineering professional.

The human-digital relation of this professional in this work practice led to the requirements of the same technical engineering skills since the work process remained the same and can be conceptualised as automation. However, the notion of relearning how to do things which appeared in the interview results indicated that some form of a change of the work process occurred and caused a

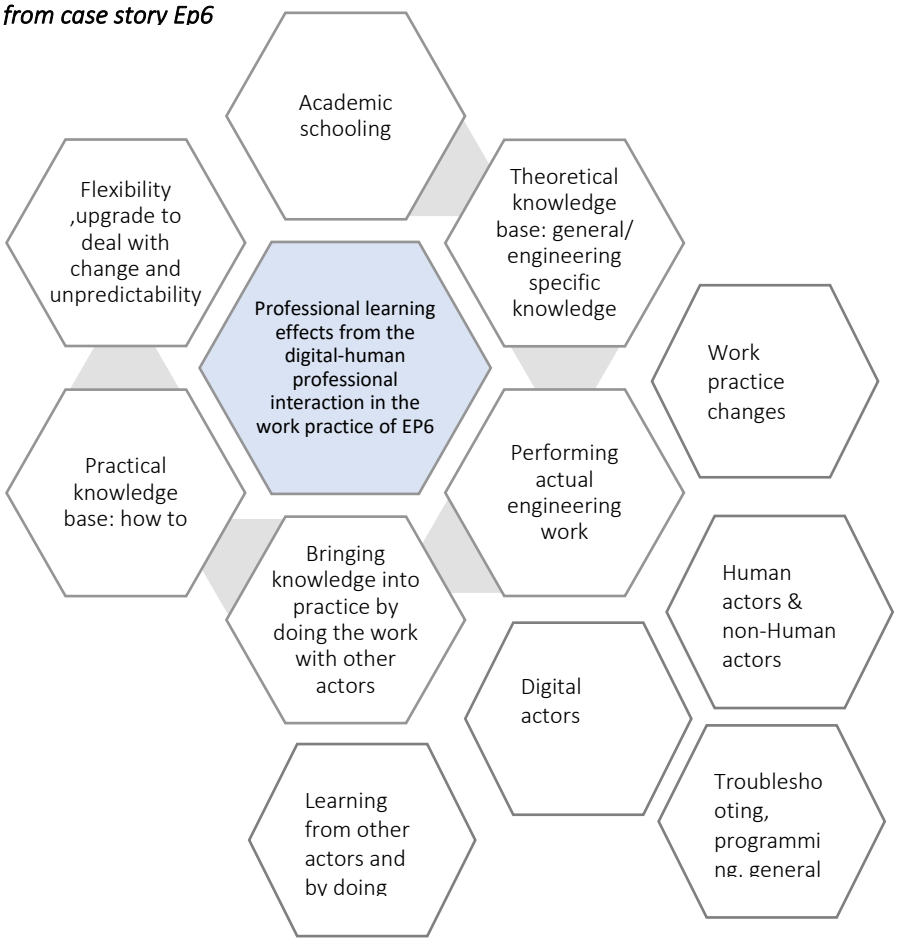
need for relearning. This latter may be conceptualised as a form of innovation. In regards to the human capabilities to *enact* upon the digital technologies such as simulation, were found in troubleshooting and installation but also programming skills which implies that the unpredictability of the digital *actor* acting was relevant and skills such as troubleshooting appeared beneficial to *enact* upon and anticipate these acting's. The relearning how to do things also implies a notion of practically relearning which happened through doing the work. The main preferred learning mode of learning by doing the practice further supports this view. At the same time, the professional acting's of this professional may also be understood to have relied on a theoretical academic knowledge base since the technical engineering skills and knowledge were argued to have remained the same.

The professional learning implications that can be derived from the human-digital relations in this case story are illustrated in Figure 22. The effects are that a theoretical knowledge base containing general and engineering specific knowledge, and general skills is required which can be learnt in academic schooling. Although it was argued by the professional that this was unique to his specific schooling as opposed to other engineers. The practical work part is which should be learnt by *performing* engineering practice which is by doing the actual work with all its participating human and non-human *actors* and learning from colleagues. Learning to work with the digital technology *actor* relies on a strong disciplinary foundational base supplemented with some technical skills to overcome unpredictability and problem solving but skills such as programming would enable to fully *enact* upon the digital technology to adapt the digital technology into the work practice. Learning should allow for learning how to deal with constant change and the development of a sense of flexibility. Ideal would be a real practical professional work exposure during professional learning. The professional learning profile derived from the explorative case story of this engineering professional is illustrated below and the key learning features depicted in the hexagon's. Starting on the top and moving to the right, the theoretical knowledge base and learning in school moves on to the *performing* of actual engineering work where different human and non-human *actors* are part. Key requirements to work together with the digital *actors* remain technical skills such as programming and troubleshooting and general skills. In the engineering work, the individual knowledge is brought into practice and colleagues are of great help for this process. The focus remains on the 'how to' to deal with the dynamic forces of the

requirements of the engineering work practice of *preparing project reports*.

Figure 22.

Learning profile derived from case story Ep6



7.4 Engineering professional (Ep5) that socially *rebuilds* work practice 2

This empirical example shows a male engineer working in a medium-developed work context with a couple of years' work experience after graduation.

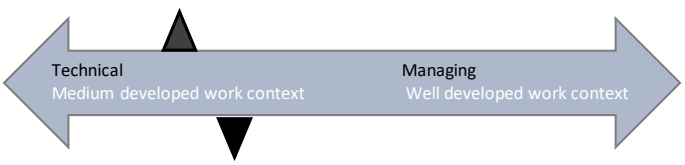
Empirical case EP5	Engineering level
empirical case EP5 is a male and full engineering qualified (postgraduate level) sub-site agent working in a larger engineering construction firm, based in a medium developed work context and operating in a local context only.	

Figure 23.

Description, context and role of empirical case EP5

The work practice of *developing construction plans* and estimation of costs for the installation of systems, utilization of facilities and construction of structures was understood as the planning for the cost side of a project. These involved calculations based on the prices of suppliers and other third parties well as the planning based on the time effort for the team directly. This professional understood it as a work process of which the procedures he needed to use were planned for. He also had to see if his estimated costs were within the budget and he also had to determine whether or not he was making money in his project. The inclusions in the practice did included general resources, time, material prices, labour prices and accommodation which fed into the task to estimate the costs. The work practice was a fair share of this professional's work as he spent most of his days on this particular work practice, although this was dependent based on the stage of at the construction project. At the start of a project it takes more than half of his workday and later it takes about a quarter of his day. The principles of the practice are discussed next in where each time, the five principles are the guidelines.

The first principle of the practice, "practice is more than the simply the application of theoretical knowledge or a simple product of learning" (Hager et al., 2012, p. 3),was used to show a move beyond knowledge residing in the individual professional. This professional, as a member of this practice, believes believed that the best way to learn this practice was to spend time with a more experienced professional and shadow them for about a week that will to the necessary practical insights. If a professional would come from another company, the process was regarded being easier as pre-existing practice knowledge exists but that had toto be transferred to a new work context. The change of the practice and having to relearn can be attributed to the use of a different kind of software but the essence of the work process stayed the same. In the relearning process, the narrow steps could be different and required relearning. This professional acknowledged that he could learn from someone coming from another company about different ways of executing the practice. This is illustrated by the quote below:

> Someone new comes in. I say ideally what should happen is they should spend about a week or so with me learning what I do and what procedures and watching, obviously if they've done the job before then it's just basically a hand-over, you see. It's like this this [name software] that I use, all the construction companies use it so it is just the way I use it may be different to the way someone else uses it. (EP5)

> Well what I learned at Campus, I still do apply that but not as much and how I did it at campus. But now the thing is and now in the position and the [specific work name] that I'm dealing with and I get mentored a lot by my manager. (EP5)

This professional had not selected any of his skills and knowledge different to work specifically with digital technologies than selections without referring to the digital itself. The same kind of skills, although fewer skills were selected The specific digital skills were mostly found in the area of general skills, management and programming which were learnt by trial and error as well as more knowledge areas such as social sciences and three technical skills. Working to interact with digital technologies is what he had learnt in school, as he had access to the resources, but he also thought that age and motivation both play an important role in learning to work with digital technologies. In fact, he argued that people in a lower work position might learn better on-site during work. At the same time, he argued that the reason they have ended up in a lower work position is related to a lack of motivation and working less in school. The comment below illustrates this:

> Well ...in my role, I learned it in school in high school and also I was afforded that opportunity ,you know to go to a good school who had all of the technologies and stuff and my parents bought me a personal computer so I could you know practice further and you know better myself. Yes but some other people on site, I would say... like this lady that I just spoke about she.... she knowns here and there but I would say she learnt her stuff on site. She wasn't afforded with the same opportunities as what I was. but there's also like say opportunity, like how you did in school. It goes back to like the general laborers on site. The guys with pick and shovel of digging holes and you know. All these things we have learned from school. But they didn't do well in school. You see. That is why they are where they are now. (EP5)

In this work practice, the managing professional selected five knowledge areas required for this practice, ranging from three engineering disciplinary knowledge areas to two social knowledge areas. The preferred selected learning mode in the survey and confirmed in the interview were either *from a colleague at work* or *in school*. He elaborated that what he had learnt from his mentor in practice had taught him how to really do the work. Also, he used his school-acquired knowledge to some extent, but this is not what he saw as a daily practice. Instead, he saw it as a foundation from where he built forward in practice. He explained that the technical part of his work was which he learnt in school .Unfortunately, this technical part was no longer the focus of his work because he was no longer directly *performing* technical engineering work himself despite his job title was indicating otherwise. The comment below illustrates this:

> I would say what I learned, especially within the past year most of what I'm doing now I learned it on site from my manager. So obviously I apply whatever I know, you know the basic program Excel and PowerPoint and things like that. I did not learnt it on site when I knew that stuff but like to really learn to do things, that stuff I learned from my managers knowledge but the stuff that I did in school I used it to an extent but not daily. That is foundation that It follows on to what I studied in school. Just that I am now more into the financial side of the site planning and things like that. So, I'm not doing what I did in school. like going to say inspecting and give my recommendations and things like that. I still do that, give recommendations and [] like that. But I wouldn't personally go on site and find things off anymore. It's not my role. I would call the quality guy to go and check and see what's happening. (EP5)

This professional saw this practice as highly skilled because he selected 18 skills in the survey. When elaborated in the interview, he referred to people skills being essential for executing this practice. Since this practice entailed dealing with a lot of different kind of people, all with their own agendas. For example, the selected skills ranged from technical with five selections, social skills with three selections and more general skill selections such as critical thinking. Critical thinking was operationalised by using his intuition and predicting in advance the possible behaviour of others. Or anticipating on the possible consequences what could happen at work due to other events and then anticipating on these predictions. He learnt most of his practical work skills from his senior colleague who appeared to be a mentor and he taught him the practical tricks of dealing with unanticipated problems. Another general skill example, such as reading and listening, both also connected to people skills, he explained that he had learnt the basics in school. He learnt time management from a colleague at work. This was based on defining which tasks in work have top priority and should be solved first. In this, he took directions from his senior management and tried to solve this with his team first, but in case he cannot solve this with his team or by himself, he will ask for help from his mentor and manager. The comment below illustrates this:

> So you need to f*actor* into account how people react to certain situations on site and you know what happens... like for example maybe the client doesn't pay out on time it does happen now last week the client was not pay us on time. We couldn't pay our subcontr*actor*. So how are the people going to react because the subcontr*actor* couldn't pay his people. So they work slow. So you need to assess how people are going to react to certain situations. Maybe you can go to them and offer them a bonus. Can we meet a certain deadline... things like that. (EP5)

> He has experience in this stuff, so he guided me in that you know.... this is how the people are going to be. And that type of stuff. (EP5)

The second principle of the practice theory, "Understanding practice as a sociomaterial phenomenon, involving human and non-human *actors* in space and time" (Hager et al., 2012, p. 3), was considered next to trace the different participating members in the practice. The sociomaterial nature of the practice appeared relevant for this professional and included both human and non-human *actors*. The human *actors* who were involved were clients, who appeared to have a big impact and appearance in the practice, local contr*actors*, suppliers, people from the project team directly, and community officers who controlled alignment of the local regulations with the execution of the project. The different work roles involved in the project team directly were more diverse at the beginning of the project, with roles such as a senior site agent, contract manager, operations executive, a subsite agent and the site engineers. The practice was thus mediated by a large and complex network of human *actors* but also non-human *actors*. Non-human *actors* were indicated to be significant for this professional in this work task (90% in the survey) and ranged from mobile devices and apps to more specific tools such as BIM and simulations. Mobile devices were used as an alternative to a computer on site and improved accessing information in spreadsheets. Simulations, on the other hand, were not directly recognised by the professional but when he explained his use, it became clear that they were in fact simulations. Initially he referred to the use of simulations in forecasting the project, which was based on prices, but during the discussion in the interview, he acknowledged that he also used simulations to mimic a possible future scenario. However, when further explained, it came down to a compilation of the work with allocated time and prices and not a 'worst case scenario' or ideal future scenario to base performative decisions on. The simulations were helping him to plan, and the software he used reminded him when to order construction supplies. This software may then be seen as a facilitating decision-making party se. The comment below illustrates the sociomateriality nature of this professionals' work practice:

> So, the client is also around and then we just basically spend a lot of time with the client. Try to find out what they want and things like that. Because he's the one that we need to please at the end of the day (EP5).

> programming slash planning... now doing that to.... you know.... forecast how long the project will be, not based on productions on site labour resources. That sort types of things. You don't look at cost in that, you just look at time. So, I say for example that I need to build a wall. Yeah back to the wall. So maybe it will take two days to. Go dig and dig the foundation and other x days to do the foundation ,20 days to build a wall and plaster. etcetera and you link all your items together (EP5).

The third principle of the practice-theory, " Practice is embodied and relational" (Hager et al., 2012, p. 3), was used to develop insights into the existence and nature of relations of this engineer's practice since the principle allowed to highlight the different *actors* and their power to shape the practice. This practice is relational and embodied as it included 50 to 60 workers who reported to this professional which indicates a high level of power. On behalf of his business, he is the operational leading party of the construction project. He viewed the operational construction workers as different kind of people which he gave limited professional autonomy in the execution of their work. This professional perceived the effects of digital technology in this practice as an enhancement of human skills and an advancement of work. At the same time, he argued that it helped people to do their work with less effort and time. The comment below illustrates the notion of different people in this engineering professionals' work practice:

> Like I wouldn't say that people sit in front of a laptop like me. No, they are the people on site doing the work. And machinery and the foreman, engineers those types of people. And I prefer I let you guys do certain things. (EP5)

The fourth principle of the practice-theory, " Practices are neither stable, homogeneous nor ahistorical" (Hager et al., 2012, p. 4), was used to show the complexity of the work practice of this professional by focusing on context and change. The practice was shaped and impacted by the local context of where the practice took place because the work practice for this managing technical professional was mostly not bound to the local office environment but took place, both on the construction site directly and in his office environment, which was on site with the client:

> Depends when you say office or site because my office is on site with the client. (EP5)

This work site is specific, but only for the duration of one construction project, after which the environment may change along with the localised context, regulations and so on. The practice was contextually mediated by regulations to include workers from the communities and therefore bounded by these localised contextual features. If the practice moves on to the next location, the context might change again and thus the practice will change.

The fifth principle of the practice-theory. "Practices are emergent, in the sense that the ways in which they change and evolve are not fully specifiable in advance" (Hager et al., 2012, p. 5), was used to explore the way in which the practice has changed. The practice can be perceived as emergent to some extent. Although the professional can only refer to the last working years to

compare changes of the practice with, he argued that the practice had changed in the way that previously manual work was now automated. The practice had changed because professional time and effort reduced. But in essence the work steps involved stayed the same but the way HOW these steps were performed changed into a digital format, which is illustrated with the comment below:

> Automated, you still need to use programs and things like that to do the work but instead of sitting down with a pen and a paper and tapping into kind a what's involved you can you can do it a lot easier and you can run things for the whole month or so instead of having papers for the whole month and then filing. (EP5)

The word cloud generated from the interview transcript depicted in Figure 24 shows that different terms appeared important for this engineering professional's work practice of developing construction plans. These ranged from words which are indicating the use of specific digital technologies such as programming to words indicating processes and human *actors*, such as *people* and *planning*:

Figure 24.

Word cloud interview with case EP5



To conclude based on the case story with the view of this professional, the work practice of developing a construction plan for a specific localised project changed to some extent. Part of these changes can, like with the previous professional, attributed to the acting's of the non-human *actors* in his practice. The non-human *actors* were found in the use of mobile devices to work remotely when the professional was travelling or allowing for working on site, and basic spreadsheet used to store financial data to improve the efficiency of task execution. Simulation technologies were showing

acting's that were used to merge project data to develop the planning of finances and time. Other than the first engineering professional case, the use of the digital technologies can be understood as basic and less sophisticated technologies. The main advantage that digital technologies as non-human *actors* brought with them was that they reduced professional effort and time when the professional tasks acting's were executed. What appeared more significant in this professional's interview results of was the role of the human *actor* component in his work practice. A high share of different human members in the practice were *performing* their professional activities and were impacting the execution of the practice. The human *actors* ranged from colleagues that helped this professional with his own professional responsibilities, to social and material regulations- non-human acting's- that for example required the regulated use of members of the localised community. The social nature of the practice appeared because acting's from other human *actors* appeared, and this professional had obtained most of his practical work knowledge from a colleague who had acted as a mentor.

7.4.1 Summary of case story Ep5.

In sum, the role of digital technologies in the work practice of this human engineering professional were understood as partially *performing* non-human digital *actors* acting on professional responsibilities such as those capabilities found in the area of limited reasoning capabilities such as calculations and planning which can be conceptualised as automation. Regarding individual professional responsibilities, time and effort reduction were the main positive consequences for this professional but also automated work activities such as ordering supplies were seen in the human-digital interactions in this work practice from the perception of this engineering professional.

The human-digital relation of this professional in this work practice led to the requirements of relearning how to use software for the same work process which was best to be learnt in practice by imitating a more experienced professional to gather the required practical insights. Other learnings also appeared preferred to be learnt from another professional who could function as the mentor and possessed the tricks how to do things in practice. In regard to the human capabilities to *enact* upon the digital technologies such as modelling simulations and spreadsheets remained the same and were mostly located in general skills but programming also appeared relevant for this professional as potential to fully *enact* upon the digital *actor*. These skills were learnt by doing the work through mechanisms such as trial and error. More individual knowledge areas were required to work with digital technologies such as those found in social sciences and some engineering specific technical skills which were learnt in school. An important insight was that motivation to learning and availability of the resources during learning were essential to become digital capable. The relearning how to do

things also implies a notion of practically relearning which happened through doing the work. The main preferred learning mode of learning by doing the practice through a colleague to really learn how to do the work and how to deal with other human *actors* further supports this view. At the same time, the professional acting's of this professional may also be understood to have relied on a theoretical academic knowledge base since he argued that the technical foundation of his work was learnt in school.

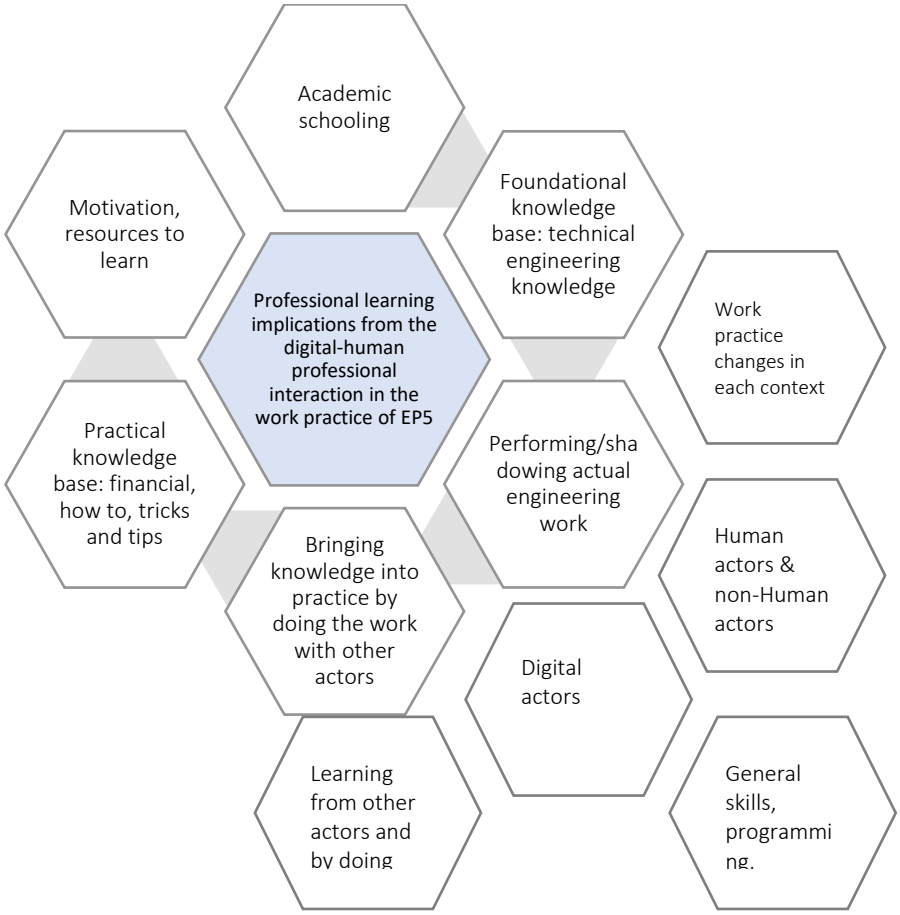
The professional learning implications that can be derived from the human-digital relations in this case story are that a theoretical knowledge base containing general and engineering technical knowledge is required of which only the foundation can be learnt in academic schooling. The practical work part is which should be learnt by *performing* engineering practice and following other experienced human-*actors*. All acting's of other human and non-human *actors*, such as those of clients and regulations can only be understood in practice through own or others experience.

Learning should allow for learning how to deal with contextual dependent variances such as using a different kind of software for almost the same work process or how to deal with localised regulations or specific kind of people. Ideal would be a real practical professional work exposure during professional learning in where exposure to all actors of the practice is included but the main guiding party in the learning is another more experienced engineer.

The professional learning profile for this engineering professional is illustrated in Figure 25. The professional learning profile derived from the explorative case story of this next engineering professional is illustrated below and the key learning features depicted in the hexagon's. Starting on top and going right again, the foundational knowledge base and learning in school moves on to the performing and shadowing of actual engineering work where different human and non-human actors are part, such as basic modelling and spreadsheet digital technologies. In the engineering work, the knowledge is brought into practice together with colleagues, but mentoring is preferred for this process. The focus remains on the practical knowledge base and 'how to' to deal with the dynamic human forces of the requirements of the engineering work practice of developing construction plans. Learning relies on motivational forces and the resources to learn.

Figure 25.

Learning profile derived from case story Ep5



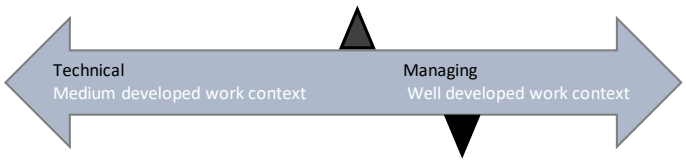
The two first case stories highlighted that the 5 principles of practice as organising analytical principles for the data showed that there is more to do with learning for work practice than just individual skills and knowledge. Also, the emergence of a network appeared in where both human and non-human *actors* were showing actions that impacted upon each other and upon the work practice. This was the case in both work practices, although the first was significantly more impacted by the non-human while the second was more impacted by humans. The next two professional case stories, each again from one core engineering work practice, are strengthened by the application of the principles of ANT in where relations between the different *actors* in the network were traced and visually depicted in a network diagram. For the first empirical case is a zooming in on the relations with digital technologies as non-human members of the practice exemplified in a separate ANT figure. The second case story follows with a depiction of the whole network of the engineering professionals' practice to show the strength of tracing all *actors* and their actions in the network.

7.5 Engineering professional (Ep7) rebuilds work practice 1 by coordinating

This third case that is discussed shows a male engineer working in a medium-developed work context with both managing as well as technical operational responsibilities working within his own structural engineering discipline as well as operating interdisciplinary with other engineering disciplines.

Figure 26.

Description, context and role of engineering professional case (ep7)

Empirical case EP7	Engineering level
empirical case EP7 is a male and full engineering qualified (postgraduate level) structural engineer with operational managing responsibilities working in a larger engineering construction firm, based in a well developed work context and operating in various countries across the globe.	

The practice of *preparing project reports* and document project activities and data of this engineering professional with managing responsibilities was perceived as developing a design report which included a lot of drawings. He initially viewed the practice as the end goal, his deliverable of the final report as per the request of the client. The investigation with the information that comes in the report preceded the final report although not all preparation work founds its way into the final report. The types of report entailed technical specifications, drawings and the final writing reporting itself. The technical specification and drawing report were used by a subcontr*actor* who had to build according to the exact specifications and drawings provided in the report. The final report was more for the client and internal use as well as for authority approvals. The practice was later in the interview viewed as both a process and an end goal because it was a journey to get to a point where one could be happy with the result. The work practice was significant because it took about a quarter of a project in terms of time which was mostly spent on checking calculations and other work of others. The principles of the practice are discussed next in where each time, the five principles are the guidelines.

The first principle of the practice, “Practice is more than simply the application of theoretical knowledge or a simple product of learning” (Hager et al., 2012, p. 3),was used to show a move beyond knowledge residing in the individual professional.. This engineering professional learnt by doing the practice. Learning for practice for this professional took place by doing the work in practice and relied on the ability to upscale oneself. Being pro-active was and able to ‘keep up’ was also

essential. This professional's personal view is that if one could not learn, one could not stay ahead. This view is illustrated with the comment below:

> I would think the ability, the ability to upscale yourself is probably the first thing. Or just being proactive, being proactive probably. But other skills. I mean being able to work with people is obviously not digitally. But being able to work with people, being able to teach yourself. Is probably the main thing, because if you cannot teach yourself you cannot learn. You can't keep up. (EP7)

Although this professional only allocated 16% to learning from a colleague at work in his survey, the interview results showed a more nuanced picture. Learning for practice for this professional took place in practice by his being guided by another professional and doing the steps involved. For example, pushing buttons in a software program was referred to as an example, you just need to do it. The comment below illustrates this argument:

> Generally. We have a sort of internal training. So, look at other staff made, and this is what you're doing in a scenario. But I would say the majority of that upskilling is done by literally someone sitting next to you and saying 'press this then press this and do this'. It actually does but it does the calculation that you could do by hand but it's faster. And it's a little bit more sophisticated. (EP6)

One of the skills, writing, was learnt by using intuition and building on what was learnt in school. The process had become synthesized to that which was learnt in school since at work, references in writing were only used straightforward and bullet points were preferred above full sentences, which was the opposite of which was learnt in school. Interestingly, this professional selected problem solving as a skill and he elaborated that he did not perceived engineering as a core problem-solving practice as explained that *performing* engineering was still possible in a service delivery way without delivering a problem-solving practice.

> So, learning ... the person learns the quickest gets it ahead the quickest and get some solutions. So being critical of thinking as well, as this is important because it cuts straight to the point & Just put it like this... I like to work and not think about anything and just go day in and day out and just automate stuff... that's not problem solving that's just service delivery. So, problem solving is. Problem solving is getting paid to build that... to design that... that is complex problem solving, because everything we do has not been done before. It is not a kind of service delivery. Yes you deliver a service. But your service is actually solving a problem. It is just an example, but I mean ...if I go do a shopping centre. Yes, there's a bunch of things in there that come up as a problem and you consult it, why is it happening? (Interviewer) 'Yeah.', So well , I mean it's difficult. You can think about as a complex mathematical thing but if it's coordination, it's a problem that needs solving. Or

> is it setting up your BIM model, it's a problem that needs solving. Well it's just, you can do stuff that's just service delivery and I'm sure you can make a good living out of it but it is not complex problem solving. (EP7)

The work skills required to execute the work practice were all six general skills and learnt by either trial and error or intuition. In the interview, the professional elaborated that the things they were doing were so complex that one needed to be able to analyse a situation and quickly came to a solution and then proceeded to test its applicability. He argued that work experience is essential because the work practice emerges in practice and practicalities cannot be captured before they happened. He thought that people who cannot make the move to quick responses were not aware of their practice and are difficult to work with. For example, they could take too long to think, and time was money in their work. The comment below illustrates this:

> I think it ties in with the things we're doing are so complex. You got no idea what the right answer is when you start. so that's where critical thinking is pretty important. So, you need to be able to … Analyse the situation, propose a solution and check if the solution works. Then you cannot start with; I know what the solution is and we're just going to do it. You've got to know what things is going to work and then you need to test it. Yes and that's why experience in our industry is so important because some of the things you can't think out if you haven't seen it before. No, it's not. It's just not possible. However, some people do tend to pick it up quicker than others. Some people just learn that on the fly. (EP7)

The work knowledge that was selected in the survey only included three areas, two social and one disciplinary. When elaborated in the interview, the professional explained that most of his learning was by learning on the job, because he argued that only then do you learn how to deal with people. He further mentioned that knowing-how to approach people and meet their needs is essential in his work practice and is something he developed over time by just doing. The comment below illustrates this individual strategy:

> Well we did some management courses, but I think where you learn the most is still on the job. I think the biggest thing about management is learning to deal with people. That doesn't time with the technology…it's all about being able to meet people and knowing how to approach. you change your approach with people. It is something, that some people do better than others, but it's something you develop over time. It's not like somebody is born with it. Some are just a little bit better in it. (EP7)

The need to work with more ""sophisticated" digital technologies is essential was argued to be essential and one required upskilling to work with these digital technologies. Not complying meant one would need to be going out of routine and transfer into a managerial role. Even the latter case, some upskilling was perceived to be required since you have to understand the processes to make decisions. Specific skills to work with digital technology focused on programming, systems analysis and systems evaluation. These were learnt by using trial and error on the job. The knowledge was similar to that selected in the work practice without connecting directly to digital technology. He differentiated about understanding how things work different and mastering working with them. Programming was in his view, essential for an engineering professional in this practice and he experienced digital technology as part of their professional nature that could no longer be ignored to be able to move forward. The comment below illustrates this:

> I mean even if you look at the BIM, that's probably the biggest shift in our industry in the last five years and it's now the norm. In five years' time if I cannot programme, you're redundant. I am already seeing that. But in five years you will be redundant if you haven't got the programme skills. Especially in my industry and the main, BIM is already ...if you cannot do BIM, you're already redundant. Then you've got to be at least at a managerial level where you're not part of the routine. But… but, even that ... even then, if you've got no background on what that is will ...at least not having the essentials...you are redundant. Not just that. imagine that a manager is not understanding what he is doing. That's dangerous. It's dangerous by agreeing... to agree to things that you have no idea what the implications are. So, if you agree to a certain level of detail on your BIM model and you don't understand what it means. You can cost your company quite a lot of money. (EP7)

The second principle of the practice theory, "Understanding practice as a sociomaterial phenomenon, involving human and non-human *actors* in space and time" (Hager et al., 2012, p. 3) was considered next to trace the different participating members in the practice. The practice of this professional can be seen as sociomaterial to a high degree because both human and non-human *actors* were constituting the practice of this professional. In the case of the human *actors* that were involved, these were as follows: clients, who gave their specific directions, the project director who had the overseeing role and the technical director who was the final decision-maker. This professional with managing responsibilities led a team of 11 engineering professionals with also have technical professionals (drafters) underneath them. Non-human *actors* involved were digital technology software such as BIM, big data and CAD with 70% of use opted in the survey in this core work practice. The professional elaborated during the interview that the models and checking them was

the core of his work and then the deliverable they produced was based on what they did with BIM. The use of Big data is focused on making a large amount of information manageable and manipulate and making sense of the data

> And the coordinated models and all those things. And that's pretty much the bulk of the work. So that's pretty much the bulk of my checking as well... is actually in the drawings itself. a hum... and that's a deliverable that we produce based on using the BIM. Now the data analytics has more to do with the design. Because we've got such large structures and we got so much data that we need to manipulate and make sense of. (EP7)

Simulations were used to put the specifications in and see what the consequences in a specific real-life situation were. For example, simulating the performance of the structure by specific external environmental forces was. This process of simulation fed into the process of the practice and coordinated the activities in the practice as the professional team based the decisions on which was modelled in the BIM system. The performances of the building and the software is shown in the comments below.

> Yeah. well it depends on how you classify simulations because we use [x software] so in essence... We do analyse the building which simulate whatever it is going to do. So, we do it for the whole building. (EP7)

> So there's a legislation and a codified approach on how to model real world situations. Obviously, there's certain f*actors* that they're building to make it safe. but essentially. Physical characteristic is obviously something we simulate in structural. and then. External f*actors* on to the physical properties. In other words. What loads, wind blowing on the wall... So that...we do simulate the models for. So yes, we we've got actually pretty sophisticated models that we simulate wind with. Which is probably world leading at the moment. (EP7)

This professional indicated that there was a need for everybody in the practice to work with BIM, even technical and operational staff. The comment below illustrates this:

> I mean even if you look at the BIM, that's probably the biggest shift in our industry in the last five years and it's now the norm. In five years' time if I cannot programme, you're redundant. I am already seeing that. But in five years you will be redundant if you haven't got the programme skills. Especially in my industry and the main, BIM is already ...if you cannot do BIM, you're already redundant. Then you've got to be at least at a managerial level where you're not part of the routine. (EP7)

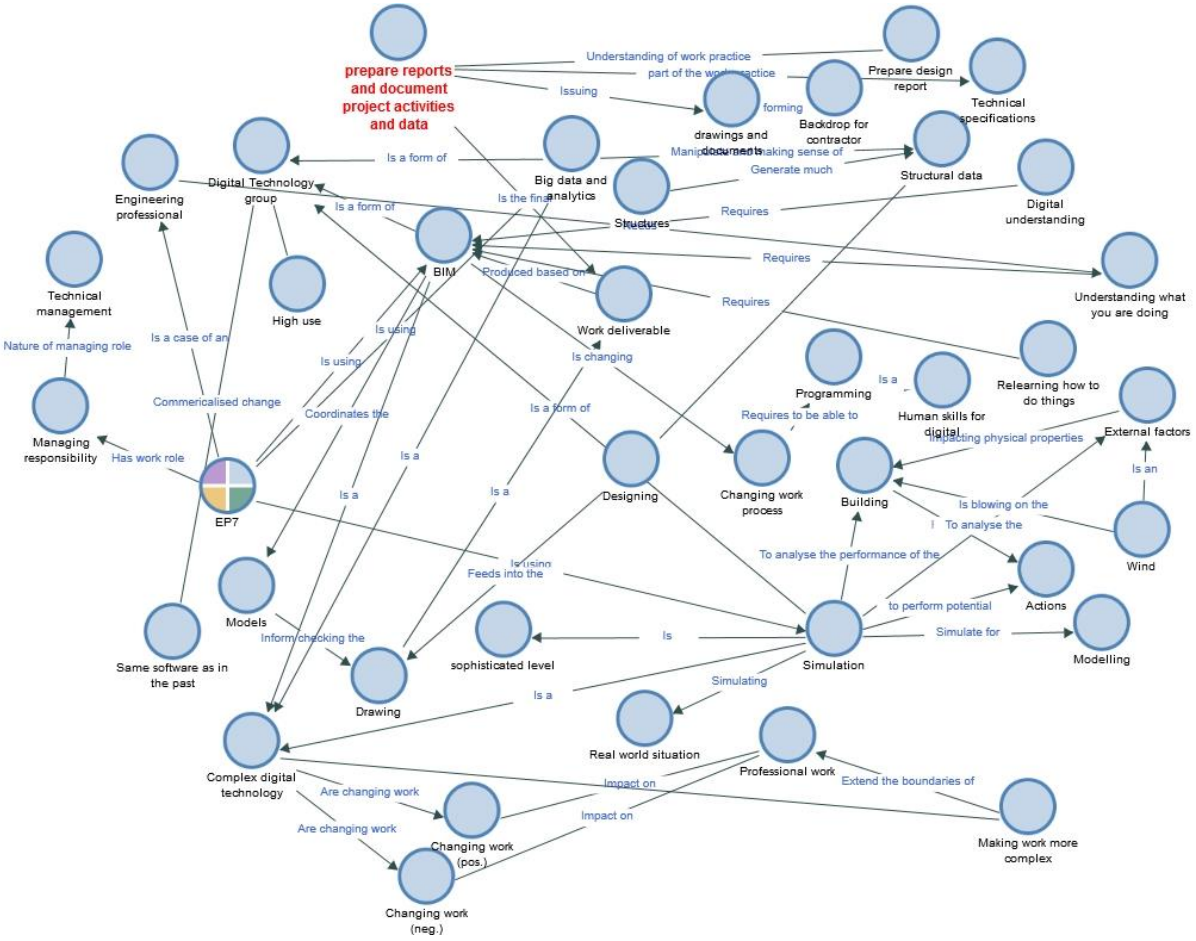
The third principle of the practice-theory, " Practice is embodied and relational" (Hager et al., 2012, p. 3), was used to develop insights into the existence and nature of relations of this engineer's practice since the principle allowed to highlight the different *actors* and their power to shape the practice. The practice of this professional is mediated, embodied and at the same time relational. Firstly, because the professional was physically checking the work of the human *actors* working in his own technical team. He was personally involved to ensure that team performances were checked because it could have major consequences relating to safety and money. And secondly, another aspect was that the professional was aligning the work with different disciplines to make sure all was coordinated together. The professional viewed himself as involved in the practice and had concerns about people who were not able to see the bigger picture of a project and were only using their own [disciplinary] tunnel vision. The comment below illustrates this:

> Certainly, you've got a client. The client expects a certain level of quality and coordination between different disciplines. So that's also the other aspect. uhm, I think those are probably the main three things. It's making sure that's safe. Making sure that it's money wise good and making surely sure that it's coordinated with all other disciplines… because it just helps the process (EP7)

Next, the relational principle of the practice was made more explicit by tracing the different *actors* and their performances through applying approaches from principles found in *Actor* Network Theory. Figure 27 is a relational map where the relations between humans and non-humans in the practice are exemplified by tracing them based on the interview results. This depiction below must not be confused with a whole *actor*-network visual where all *actors* and relations are mapped, and no single direction connections are used because of generalised symmetry which was explored in Chapter 4. One such visual is depicted later in Figure 28. The current figure acts as a minimalised and overfocused relational network, which is however not the intent of the ANT theory in its original state, but allowed me to focus more explicitly on the human-digital relation in the practice which are central in this thesis. This approach aligns well with adopting a toolbox approach in using sociomaterial theories as discussed in Chapter 4 by inviting relevant role players (approaches) in and by not inviting others

Figure 27.

Relational map from interview case EP7. Developed with QSR NVIVO 12 Plus



Note:
The visual shows the limited relational map of work practice 1 seen from the standpoint of practitioner 7.
The data is based on the STWL-survey and the interview with this professional.
The relations between the different research constructs of learning, skills, knowledge, human and non-human actors are traced.

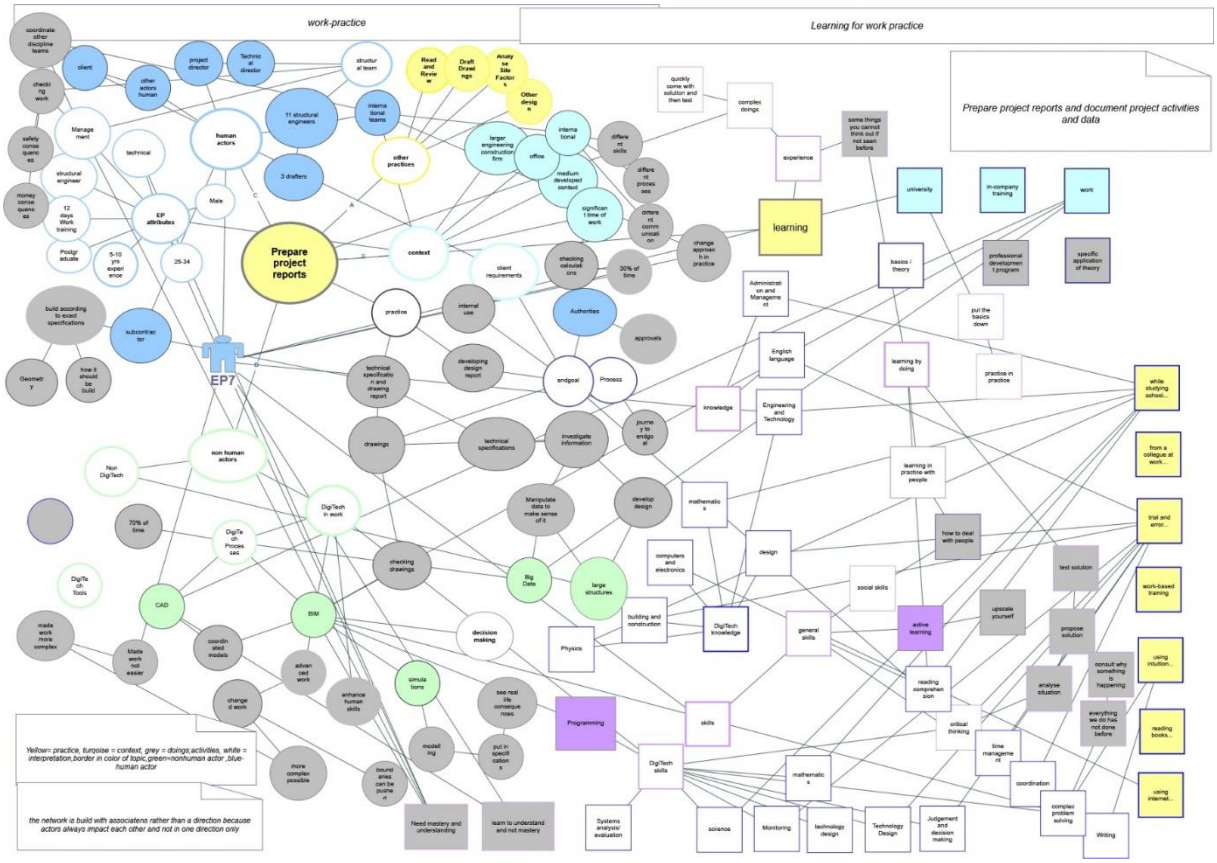
The *actor*-network – or relational map – depicted in Figure 27, shows the main relations between this engineering professional and digital technologies in the work practice based on manually tracing the interview and by using the mind map option in the NVIVO-12-Plus software to store the network. The blue circular nodes show the different *actors* in the practice or main actions and the small arrows show the association between them. Associations could be a linear effect from one *actor* on another by *performing* a specific action or from one performance on another. An arrow shows the direction of the performance and an association line does not include any direction or is symmetrical. What can be seen on the map is that the specific digital technologies of BIM, Digital analytics and Simulation were impacting on professional responsibilities, such as decision making, but

were also impacting on the practice components directly, such as on design reports. The digital technologies shown in this network are *performing* some of the work activities *performing*'s from the engineering professional. The digital technologies were also impacting the work practice and professional at the same time since they made the more complex doable but at the same time extended the boundaries of professionality. The network, which was resulting in multiple nodes (*actors*) and performances (relations), is useful to trace analytically the relations between human and non-human *actors* and fits well with common approaches in academic research using ANT approaches or sociomaterial approaches.

Figure 28 illustrates all human and non-human *actors* in the practice of this professional. As opposed to the previous figure, this ANT network illustration has traced all *actors* and performances until no further information could be derived, based on the interview and a few relevant survey items of this particular professional. The circles show the *actors* in the practice in where the practice is central, and no *actor* receives any upfront agency. The lines are non-linear and indicate an association which presumes that associations can work symmetrical and both ways. The green circles indicate the digital *actor* whereas the blue circles indicate human *actors*. For instance, the figures show that BIM has advanced work by including coordinated models generated with CAD. This on turn, made the more complex possible and it changed the work practice. It therefore made work more complex and easier at the same time for this professional which required digital mastery and understanding. This thick description can be continued among all possible combinations of the depictions in the network but will not make things clear. Therefore, the visual representative power of the ANT-network illustrated in Figure 28 is on its own a data analyse and a result.

Figure 28.

ANT network work practice 1 seen from the standpoint of EP7



Note:
The visual shows the ANT network of work practice 1 seen from the standpoint of practitioner 7.
The data is based on the STWL-survey and the interview with this professional.
The relations between the different research constructs of learning, skills, knowledge, human and non-human actors are traced.

Source data: 2018-2019 STWL-survey (de Munnik, 2020) & Interview with EP7 (de Munnik,2020)

By focusing on the association lines in the figure, the relations between human and non-human *actors* appear and their connection in the work practice. The figure shows that multiple relations exist in this network of the practice from the viewpoint of this professional. On the left side, the depiction of the practice is included with its different *actors*, human and non-human as well as its context. The grey circles are the performances of the *actors* in the practice and by tracing their lines it appears on which *actor* they *enact* or are *enact*ed upon. By focussing on the squares and the

association lines, it is shown that learning in practice, by using trial and error on the job or learning with people, is preferred for this practice from the perception of this engineering professional. Individual skills are associated with general skills such as reading, critical thinking and complex problem solving. Individual knowledge for the practice is perceived to be learnt in school. The work practice for this professional with technical management responsibilities is mediated by the social and contextual contexts. The social context was already described in the introduction section and sociomaterial section but also contextual because the professional is bound to the local office environment behind a computer. Despite that this professional's work was physically bound to one place, coordination with other teams in other locations across the globe happened and thus that part of the practice, although not physically embodied, was not locally bounded. This brought some challenges as the culture, the way of communicating, the level of skills and processes were different in those offices. When asked if the level of skills between those global offices was significant, he argued that the level of skills within a single office was different. The comments below illustrate this:

- I'm referring to other engineering disciplines, it is just not that they are in my team responsibility. I need to work with them so I can get stuff coordinated. So, the easiest example is: There's a concrete wall. The guy that does design the air conditioning. He needs a hole in the wall because he has to put his air conditioning pipes through it. So, if that's not coordinated. it's an issue on site. (EP7)
- You will have some primary disciplines. I would say is structural. civils, infrastructure, mechanical, electrical, plumbing. And that's essentially it but the biggest challenge that we have is getting coordination because not many people do it well or do it at all. (EP7)
- All those are different, my approach with each of those places [different countries] is different. Because not only is the culture different. the level of skill is different. The language is different. The expertise is different. So, you've got to change your approach for each and every one. (EP7)

The above automatically refers to the **fourth principle** of the practice-theory. " Practices are neither stable, homogeneous nor ahistorical" (Hager et al., 2012, p. 4), was used to show the complexity of the work practice of this professional by focusing on context and change.. Because it is shown that each context requires a different approach and execution of the practice.

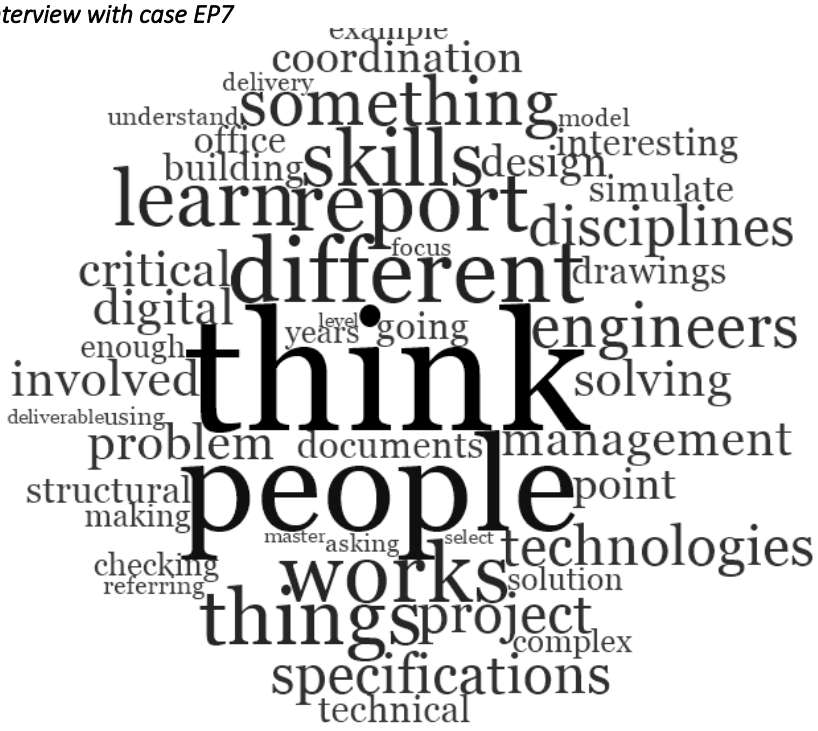
Building on the **fifth principle** of the practice-theory. "Practices are emergent, in the sense that the ways in which they change and evolve are not fully specifiable in advance" (Hager et al., 2012, p. 5), was used to explore the way in which the practice has changed. The practice can be

understood as emergent because the work changed under the impact of digital technology in the way that more complexity in this professionals work is possible. Boundaries were extended, and thus challenging what was possible in practice. The professional experienced that digital technology completely enhanced human skills but at the same time advanced his professional work:

> I would not, you can say. I wouldn't say it has made the work easier. It has made the more complex doable. So, it's not... it has not made my work easy. It actually made it more complex. And it just allows you to do more complex buildings. That's what it is. You can push the boundaries and much more with the technology we have now. And the tech was available 10 years ago. (EP7)

Figure 29.

Word cloud of interview with case EP7



The word cloud generated from the interview transcript which is depicted in Figure 29 shows that different words appeared important for this engineering professional's work practice of *preparing project reports*. These words were found that were ranging from activities such as drawing to words showing performances such as coordination and *actors* such as things.

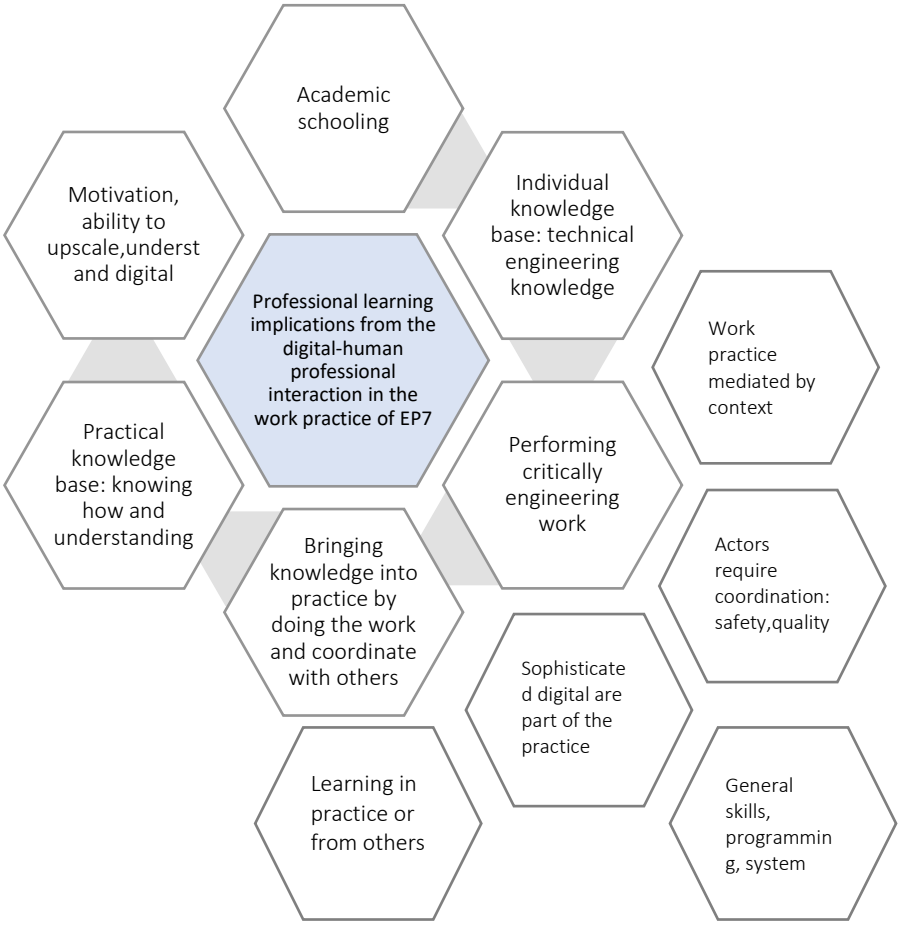
7.5.1 Summary of case story Ep7.

In the third story, EP7, a professional in a medium-developed work context, learnt the daily work practice by *doing* the practice. This was defined by a critical amount of self-motivation and the ability to upscale. Learning from a colleague in practice was also highly relevant to him. Other human *actors* in his practice are changing his practice because he had to coordinate all the different human and non-human *actors*, such as drawings, specifications and regulations in which digital technologies such as CAD and computers were also used. Of these, only human *actors* and laptops are similar to the ones found by Reich et al (2015) in a similar engineering work practice. The digital *actors* such as BIM and advanced simulations shared a significant part of his professional responsibilities. In fact, most of his professional responsibilities were dependent upon the performance of these particular digital *actors*. These digital *actors* mostly used reasoning capabilities such as simulating potential doings of the buildings in his practice based on external materiality forces and predicting what the result could be. From there on, this impacted the design, specifications and drawings of the building. The result from this shared professional responsibility was decision making which improved the quality of the work and improved safety but also challenged the professional possibilities and deliveries further as opposed to when he was not sharing his professional responsibility. In his interaction with the digital *actor*, he had to upskill himself to be able to interact with them in terms of his programming skills, systems analysis and evaluation. He sees the digital technology *actor* as part of his professional nature and as essential for his practice.

The professional learning profile derived from the explorative case story of this engineering professional is illustrated in Figure 30 and the key learning features depicted in the hexagon's. Starting on top and going right, the individual knowledge base and learning in school moves on to the *performing* of actual engineering work where a high variety of different human and non-human *actors* are part whom require coordination for the benefit of the practice. In the engineering work, the individual and shared knowledge is brought critically into practice and sophisticated digital *actors* are essential for this process. The focus remains on the motivation and ability for a professional to upscale and understanding what is done, understanding digital *actors* as nature of the practice is core to this engineering professionals' belief and ' knowing-how to' to deal with the dynamic and complicated forces of the requirements of the engineering work practice of *preparing project reports*.

Figure 30.

Learning profile derived from case story Ep7

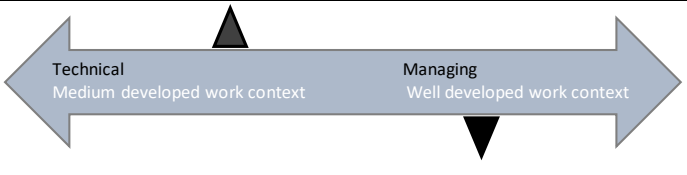


7.6 Engineering professional (Ep3) that socially rebuilds the work practice 2

This empirical case of the practice of *developing construction plans* shows a female engineer working in a well-developed work context with a couple of years' work experience after graduation.

Figure 31.

Description, context and role of empirical case EP3

Empirical case EP3	**Engineering level**
empirical case EP3 is a female and full engineering qualified (graduate level) junior electrical engineer working in a larger engineering construction firm, based in a well developed work context and operating in various countries across the globe.	

The practice of *developing construction plans* and estimation of costs for the installation of systems, utilization of facilities and construction of structures was for this professional understood as

making a design based on client requirements, assessing the site location to see the specific context, developing plans and estimating costs for the required project. From there onwards, the plans were developed and written up in a report. The professional experienced the practice as a process with steps involved and the practice was changing, based on colleague and client feedback.

The principles of the practice are discussed next in where each time, the five principles are the guidelines. Building on the first principle of the practice, "Practice is more than simply the application of theoretical knowledge or a simple product of learning" (Hager et al., 2012, p. 3),was used to show a move beyond knowledge residing in the individual professional. The professional indicated that she learnt most of her basics for the work practice in university and had built forward on this base in practice. She perceived the theoretical part as what was learnt in school and the application as that happens at work later on. The professional perceived that she learnt a significant part of her practice from senior engineers as well as through work-based courses provided by the company as well as by suppliers. She viewed her professional learning as a combination of school and practice but preferred learning from other engineers as they tend to know how to apply the theoretical knowledge in practice. The comments below illustrate this:

> So, I learned all the basics in uni. So, for example the fog levels and short circuits and all those things I learned that in Uni. Like the theory. But then I learned everything else; like how to apply it. How does it affect the building, the switchboard the… like, It's more specific here. I learned all the theory in University, and I have like a pretty strong base because of University but then this is a lot more specific. I learned all the specifics in the work. (EP3)

> It's a combination of a lot of things. So, I've learned a lot from senior engineers. A lot! they take their time and they took the time with me and they taught me a lot of. Things. Yes. But [company] also has like a continuous development program. They get Suppliers and other people to present to the whole team. So, in that case in that case we learn with the rest of the team. And also, by my own. So, it's a combination of everything. 'If I wanted to choose only one, I would choose Learning with a senior engineer. Because a senior engineer has all the information from University so he can help me on that, and he can also help me on all the calculations and everything. If I only had a school, then it would be a problem. Because I don't know how to apply it. I don't have the experience. A senior engineer has all of that. (EP3)

For working with digital technologies, one different skill was selected in the survey relevant for working with digital technologies specifically. This was *operations analysis* and was learnt in work by doing the work and improving upon the result. Learning from a colleague was indicated being

important for this process. One different knowledge area was selected in addition to disciplinary, technical, and design knowledge required to work with digital technology. This was telecommunications which was learnt by trial and error because no schooling was received for this. Working in a specific context with simulations was learnt through supplier training or from a colleague who helped her out by acting as a role model or mentor.

This professional learnt most of her practice knowledge in school except for design knowledge. She learnt design while working, by designing specific solutions, improving them and implementing them. Furthermore, the professional selected about 10 skills in the survey required for this work practice, ranging from general skills such as writing and reading to more technology-specific skills such as equipment selection and technology design. Her learning for work was varied with different modes such as school, work, reading books and using intuition plus colleagues. However, the focus in the interview was on learning from professional experience which happened in the work practice and from colleagues at work. She admitted that she had a strong foundational schooling base but that learning in practice about the tricks is essential. Especially when unpredictability and time pressure were playing part. The comments below illustrate this:

> This is something that was not absent but that not all universities have. In my university they care a lot about you trying to really understand everything you're doing. Like for example in Maths. They would ask you to prove everything even the simplest of things like even two plus two. They would ask you to prove it. As the base. So, I just think that taught me a lot of critical thinking because it's more like OK I don't take everything for granted. I really want to understand why this is happening and why are we bothering to do these calculations or not. (EP3)

> Because when I started the job. Like in Uni its easier because it's like OK I have a test this day and I'll take just a week to study like fully for that test and that's OK. So, it's like there's an order to things but in here, the client gets like this to you on one day and he's like OK I need it before now! And you have to do it right away. So, I've been, like having this client for a long time now and now I actually tried to review everything before so it's not a surprise. So, I can say like: ah yeah, I've looked into this, and this and this is what happened. Instead that I'm having to overwork for two days because they want something right away. So yeah that's something I learned because of the type of client and everything. Yes, it's easier to learn in the work. Knowing the people. (EP3)

Building on the **second principle** of the practice-theory, "Understanding practice as a sociomaterial phenomenon, involving human and non-human *actors* in space and time" (Hager et al., 2012, p. 3) was considered next to trace the different participating members in the practice. The

sociomaterial nature of the practice becomes apparent in this professional's perception of the practice because different human and non-human *actors* were involved in the practice. The human *actors* involved in this practice of which this professional is a member, were ranging from clients, team colleagues to the project manager. Roles in the network were ranging from project manager, mechanical engineer, senior electrical engineer, an advisor who was more involved with the client directly, the fire engineer and the structural senior and junior engineers who made up the rest of the team. Non-human *actors* involved were extensive and range from electrical engineering tools, disciplinary specific tools, to digital technology tools and processes. Digital technologies were focused on drawing the designs to inform the decision making and getting approval for the final execution of the project as well as modelling tools and reporting tools. The non-human *actors* included simulations as a form of digital technology process and are used to imitate a future possibility such as a possible failure so that the professionals could to act on this beforehand to improve the design and reduce mistakes. The starting point in this process was the worst-case scenario and following design. The practice involved directly working with electronics such as switchboards as the possible project outcome of the practice. The quote below shows the professional's perception of the non-human *actors*:

> I do use a lot of tools in general for doing the plans is not just drawing the plan but it's more about calculating stuff and simulating and things. (EP3)

Building on the third principle of the practice-theory, "Practice is embodied and relational" (Hager et al., 2012, p. 3), was used to develop insights into the existence and nature of relations of this engineer's practice since the principle allowed to highlight the different *actors* and their power to shape the practice. Learning for the engineering practice of *developing construction plans* is understood to be relational and can also be regarded as embodied. First, the practice is embodied in time because it this specific work practice was an essential part of the complete work practice of this professional since the time spent ranged from 70% to 40%. The level of decision making for the professional as a member of this practice was limited in the sense that specific allocated tasks were within her full decision-making capability however, in practice, the decisions were made together with her colleague and senior engineer. The professional perceived the changes associated with digital technology as something that automated human processes and enhance human skills, bringing better which resulted in time management. This free time was then spent on thinking about other essential work things to improve her practice and quality of work. The impact was thus perceived as an enabler for building a deeper and better understanding of the work practice and enabler of the improvement

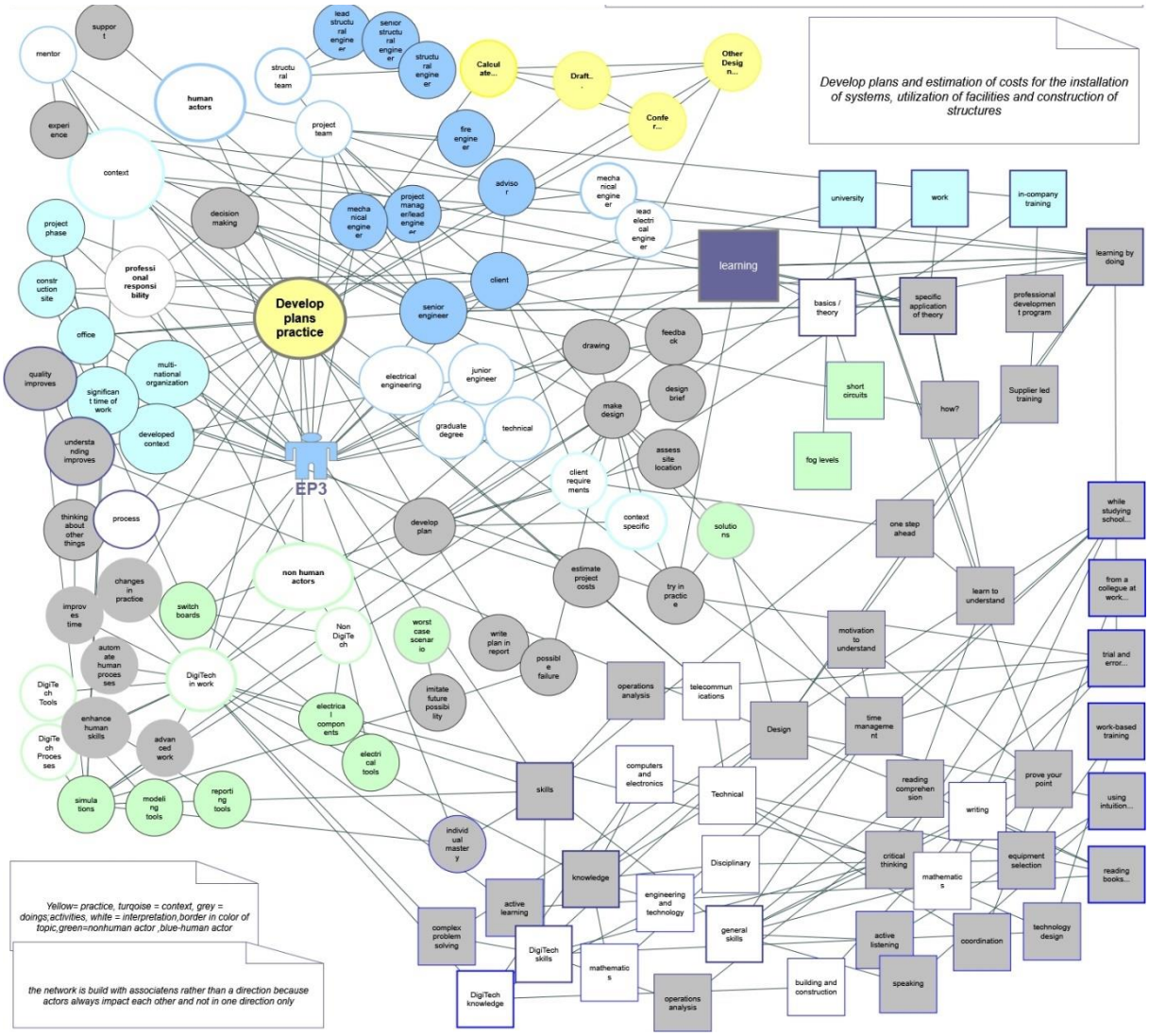
of quality. Professional responsibility seemed to shift towards non-human *actors* in some regards. Digital technology enhanced human skills in the work and at the same time advanced the work. The comment below illustrates the relationality with other human *actors* in the practice.

> Well it's hard because we, with the senior electrical engineer we're very like we're doing a collaboration like he doesn't make the decision and I don't make the decision it's more like OK let's discuss and we discuss and then end up with the final decision. But if for example, if we have a very specific task then I have complete control over about it and then I'll just show it to him. (EP3)

Figure 32 presents similar to the previous section a visually traced *actor*-network theory illustration but this time for this professional and for the practice of *developing construction plans.* The figure illustrates the relationality of the practice by visualising the practice in an *actor* network in which human and non-human *actors* and their relations are traced and visually depicted. Although the visual is complicated, what can be seen are the associations between *actors* in the practice. It follows on the guidelines for applying an ANT approach where it does not centre, nor allocate meaning to any of the *actors* or relationships. What can be seen among the circles, in relation to the previous section on the five principles of practice, is that both the human *actors* (blue), non-human *actors* (green), their context (turquoise), their performances and actions (grey), and also their relationality (association lines) are traced and depicted. The network also depicts how connections to professional learning were made by connecting the learning information from both the survey and interview in the squares to those of the practice.

Figure 32.

ANT network of work practice 2 seen from the standpoint of EP3



Note:
The visual shows the ANT network of work practice 2 seen from the standpoint of practitioner 3.
The data is based on the STWL-survey and the interview with this professional.
The relations between the different research constructs of learning, skills, knowledge, human and non-human actors are traced.

Source data: 2018-2019 STWL-survey (de Munnik, 2020) & Interview with EP3 (de Munnik,2020)

Building on the **fourth principle** of the practice-theory. " Practices are neither stable, homogeneous nor ahistorical" (Hager et al., 2012, p. 4), was used to show the complexity of the work practice of this professional by focusing on context and change. The practice can be understood as being shaped by the historical and social contexts. For example, the practice was specific to the requirements of the client and the site in where the project item had to be placed

(electrical components) and was thus part of a larger localised and context specific project. The engineering professional in this practice had an office on site, with the client who thus shaped the context of the practice. The comment below illustrates this view:

> Certainly, you've got a client. The client expects a certain level of quality and coordination between different disciplines. So that's also the other aspect. uhm, I think those are probably the main three things. It's making sure that's safe. Making sure that it's money wise good and making surely sure that it's coordinated with all other disciplines… because it just helps the process (EP7)

Building on the **fifth principle** of the practice-theory. "Practices are emergent, in the sense that the ways in which they change and evolve are not fully specifiable in advance" (Hager et al., 2012, p. 5), was used to explore the way in which the practice has changed. The practice seemed to be emergent since the professional indicated that is the practice was constantly changing. This change occurred based on the impact of other *actors*, such as colleagues from other disciplines and also clients giving their input which thus happens in practice. The two quotes below show the emergence of the practice according to this informant:

> But if it's always a process because. Well we develop some plans according to what we need but then I go to the mechanical engineers and then we change it. So, it is … it's constantly changing" & "I have seen changes but not in the software or in the technology but more about the capacity of others or myself to automate some tasks. (EP3)

> It's going to really getting better like the way we get to the clients and they may have their feedback. So, it's always a process. The end goal is the design brief. So, what the client wants. (EP3)

The word cloud generated from the interview transcript depicted in Figure 33 shows that different terms appear important for this engineering professional's work practice of developing construction plans. These range from words referring to specific digital technologies such as

simulation to words referring to the knowledge base such as *foundation* and learning such as the word *process*.

Figure 33.

Word cloud interview with case EP3



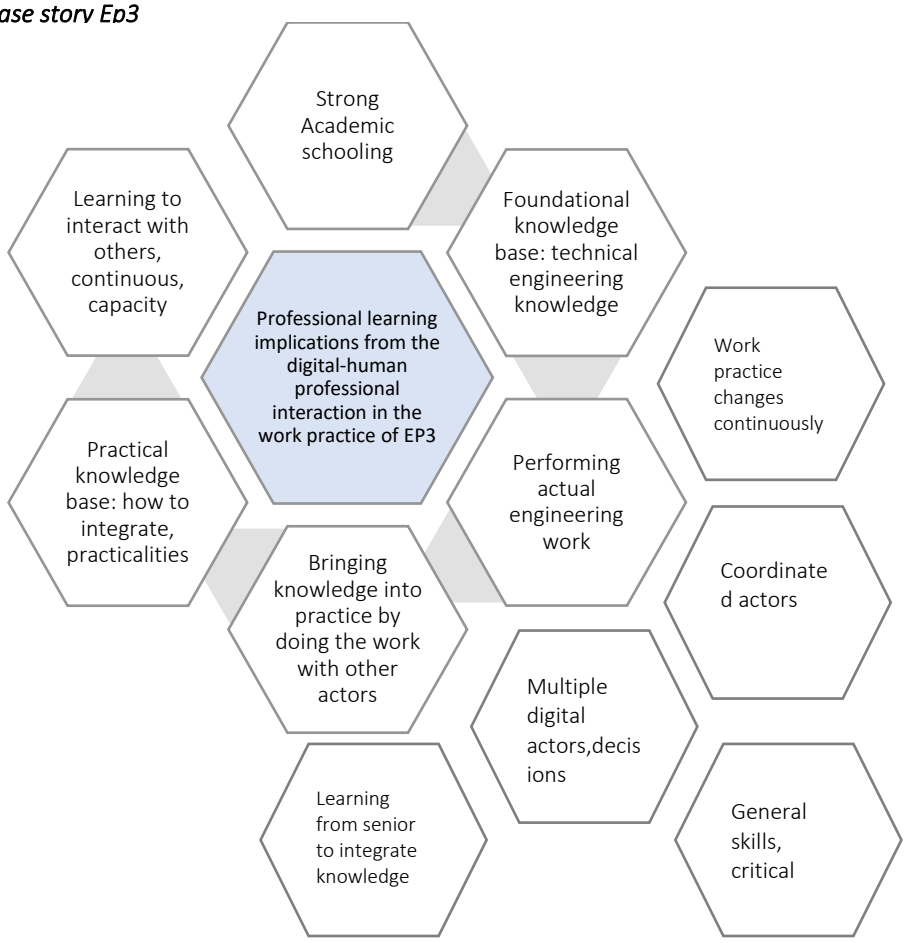
7.6.1 Summary of case story Ep3.

In the fourth story, EP3, a professional in a well-developed work context, learnt the daily work practice at work by doing the work, such as designing solutions, and interacting with seniors who could help with integrating the foundational knowledge that was learnt in school and the practical application thereof. Other human *actors* in the practice were changing the practice because the office was on site and clients were giving their guidelines as well as the changes based on cooperation with the team. The digital *actors* were significant such as simulation and drawing software with whom she shared some of her professional responsibilities such as her drawings which informed decision making for getting approval from other human *actors* to proceed in her work practice. The simulations were *performing* a vision into a future possibility and informed the decision making in where the quality of the delivery improved based on a reduction of professional mistakes. In her interaction with the digital technology *actor*, she had to learn how to do it and improve based on these doings. Her operations analysis digital skills and her general and engineering specific skills helped her to learn to interact with the digital technology *actor*.

The professional learning profile derived from the explorative case story of this engineering professional is illustrated in Figure 34 below and the key learning features depicted in the hexagon's. Starting on top and going right, the strong academic technical knowledge base and learning in school moves on to the *performing* of actual engineering work where different coordinated human and non-human *actors* are part. In the engineering work, the knowledge is brought into practice by doing the work and senior colleagues are of great help for this process to really understand and make the connection between theory and practice. The focus remains on integrating knowledge and 'how to' integrate the practicalities for the continuous changing and the dynamic forces of the requirements of the engineering work practice of *developing construction plans*.

Figure 34.

Learning profile derived from case story Ep3



7.7 A summary of the survey and interviews

The previous four case stories have illustrated the interview results by following the five principles of practice which ensured that all relevant *actors* and their performances were followed and described

in the interviews. Since Chapter 6 already showed that not one size does fit all applied to professional learning of this specific group of engineering professionals in their associations with digital technologies in work, the interview accounts described in the four case stories exemplified the nature of this unique learning profile. Common insights found among all interviews were the practical experience component in work as a learning mechanism as well as the social nature of learning from colleagues or seniors. Also common was that the theoretical base which was learnt in school was acting as a foundation from where to build forward in professional work. Surprising insights were found in the nature of the impact between digital *actor* and human *actors* in the work practice. For instance, Ep7 who was a managing, but technical *performing* professional showed an example of where work could become more difficult and easier at the same time. Easier because certain professional processes such as coordinating were automated and streamlined and more difficult because boundaries were challenged, and more was possible such as advanced simulation models and drawings which challenged the possible design of a building.

Since the four case stories were used to exemplify insights based upon the interviews, the remaining interview insights on the most important insights are condensed into tables. In the tables are both the survey and interview results shown. The tables below show the survey results in red and the interview insights summarized and organised next to the specific research construct. The combined view of the engineering professionals that selected this work practice resulting from the survey was added next to the individual professional cases. Table 25 and Table 26 depicts the views of the 5 empirical cases of the work practice of *preparing project reports*, which are summarised in a short form. Table 27 and Table 28 depicts the views of the 2 empirical cases of the work practice of *developing construction plans* .The percentages in the first rows indicate the degree of digital technology use in the work practice after which specific digital technologies are shown before the specific acting's of the digital *actors* are following and the impact notions shown. The table is based on the qualitative framework analysis which was described in Chapter 5 and on the interview data condensed in the five principles of practice (See APPENDIX L-DATA GENERATION INTERVIEW 5 PRINCIPLES). The outer right column in the tables show the survey results from all professionals who selected the respective practice but results on skills and knowledge are limited to 5-10. For a complete overview of these, I refer to the excerpts of the data in Chapter 6 about the survey results on skills and knowledge.

Table 25.

Summary of the empirical results for work practice 1 - work

WORK	EP1 Technical	EP2 Engineering	EP4 Managing	EP6 Engineering	EP7 Engineering	All 30 (Survey)
Use of Digital (mean)	2%*/ 80*	50%	81%	80%	70%	69%
Type of Digital	IOT, Simulation Laser Scanning,	Big Data Simulation	Mobile devices and apps (self) Simulations (engineers)	CAD Simulation	BIM, CAD, Big Data	Mobile Devices and apps, BIM CAD, IOT, Simulation
Data *performing*	Gathering data online to inform decision from a peer support view as well as guidelines and manuals	Transform and restructure information, connect information	-	Gathering data to inform from historical point of view the practice	Making large extend of info manageable and processable	-
Digital Simulations	Run similar scenario before implementation to see possible effects	Simulate potential future to see possible outcomes	For engineering professionals run on design and otherwise modelling on localized solutions	Runs worst-case scenario to see baseline for practice, runs realistic potential scenario	Used to see real-life consequences	-
Decision making	Based on simulations	Enabled by and based on simulation outcomes	Design decisions based on simulations	Based on simulations	Based on BIM modelling / simulations	-
Contextual (place)	Locally bound but dependent on global market	Locally bound but might depend on global market	Locally bound but dependent on global market	Locally bound	Not locally bound practice. global	-
Change of work	Completely, Core work has not changed but completion mode now digital, Maintenance is automated	Partially, Core work has not changed but other work has been automated, effectiveness has changed	Not, traditional lower level work roles have changed into digital, but those people are upskilled to other work. Higher, has changed work.	Partially, core work has not changed but completion mode now digital (automated)	Partially, core work has changed due to DigiTech (innovated). Changed design work	46.7% changed partially, 50% Completely, 3.3% Not
Work complexity impact of Digital	Same/ Less (planning has been taken over by machines)	Same	Same, for some levels easier	Same	More complex possible, boundaries extended and challenging what is possible in practice	-
Work advancement impact of digital	No, automated tasks and simplified work	Yes, but not the critical tasks	Yes, automated tasks and changed tools	No, automated tasks, more sophisticated process now	Yes	Disrupted: 3.2% No effect on: 12.6% Advanced: 84.2%

Note: This table shows the condensed insights from all 5 interviews and the 30 surveys for the research area of work
This table only shows the work practice of preparing project reports
Source data: 2018-2019 STWL-survey (de Munnik, 2020) & Analysis of the 2019 qualitative sociomaterial work and learning interviews with engineering professionals de Munnik, M. (2020).

Table 26.

Summary of the empirical results for work practice 1 - Skills and learning

SKILLS/ LEARNING	EP1 Technical	EP2 Engineering	EP4 Managing	EP6 Engineering	EP7 Engineering	All 30 (Survey)
Contribution of Digital	Time and reduction of effort due to DigiTech	Added more complexity to work but reduced time and effort	Automated work for engineering professionals, other work tool use	Time and reduction of effort due to DigiTech	Added more complexity to work	-
Enhanced human skills	Completely	Partially,	Partially,	Not, enhanced human skills engineering skills same	Completely	46.7% Completely, 46.7% Partially, 6.7% Not
Replaced human skills	Completely, Automated tasks for which no longer human activity is required	Not, Need to understand system because it can act unpredictable	Partially, Upskilling has happened. Used for modelling and computational design. Some lower levels tasks have been replaced.	Not, Automated tasks.	Not, Automated tasks, increased skills required for dealing with complexity	53.3% Not, 40% Partially, 6.7% Completely
Core skills	Same Skills: general, design, engineering specific Knowledge: Admin, Engineering specific	Same Skills: general, financial, engineering specific Knowledge: general, engineering specific, design, admin	Same engineering skills, some adaptations to digital format. Skills: engineering, general, financial	Same Skills: general only Knowledge: engineering specific and admin	More needed Skills:	Skills: Reading (87%), Writing (83%), Critical thinking (90%), Time management (67%), Listening (57%). Knowledge: Admin (80%), EngTech, Building (77%), design (63%), comp (47%)
Digital mastery and skills, learning	Yes, same as work skills. Programming required	Yes, troubleshooting, systems analysis, while working	yes, learning strategies, computers, mechanical	No, installation, trouble shooting skills, learnt while working Programming required	Yes, Programming, systems analysis, systems evaluation, while working Programming required	Yes: 52.8%/ No:47.2% Critical thinking, Reading, Learning, Maths,Monitoring, design, eng, construction
Professional learning	Mainly from other people and trial and error School 2 WBL 1 Internet 4 Trial 4	Learning on the job from mistakes, experience School 1 WBL 1 Books 2 Collegue 4 Trial 8 Intuition 2	Learning on the job, how to get the job done. In-house training and self-learning for practical things. training or study. School 3, WBT 3 Trial 5, Intuition 1	Learning on the job and from colleagues, practical job knowledge, knowing work practicalities School 2, WBT 2 Books 1, Collegue 1, Trial	Ability to upscale, try and test based on foundation, on the job learning School 3 Trial 4 intuition 2	Skills:Collegue at work 15.6%, trial and error 21.8%,study 24.3%, intuition 15.4%. Knowledge: study 39.3%, trial 17.6%, collegue 15.5%
Responsibility (digital)	Shared/Replaced/ Loss of agency?	Shared/ Loss of agency?	Shared	Shared	Shared / More agency?	-

Note: This table shows the condensed insights from all 5 interviews and the 30 surveys for the research area of skills and learning. This table only shows the work practice of preparing project reports. Unless otherwise specified, the % indicate the share of respondents who opted for the answer. Source data: 2018-2019 STWL-survey (de Munnik, 2020) & Analysis of the 2019 qualitative sociomaterial work and learning interviews with engineering professionals de Munnik, M. (2020).

The table show that an understanding of engineering work practice and professional learning for practice improves when taking the interview results into account since not only single terms such as skills are used but the context elaborating on this answer is provided such as different perceptions of digital technology replacing work or skills. The practice of *preparing project reports* is understood as both developing the actual report for a construction or engineering project but at the same time also understood as a process for all the engineering professionals as that is what ultimately needs to be addressed in the actual report itself. Differences between contexts are mainly focused on the nature of the engineering discipline and the specific role of the informant. Common views among the five empirical examples of the preparing reports practice examples show that the engineering core practice of preparing a report seen through the practice-theory lens is helpful. It shows that the practice includes different *actors*, both human and non-human, who have relations with one another and impact the practice on its turn. It further discussed that the practice is highly digitalised because none of the core work practices received a lower than 50% selection. It shows how digital technology is impacting the practice as perceived by the professional and changes that happened in a historical sense. Furthermore, the chapter showed that the professional as the human *actor* of the practice is associated with individual skills and knowledge such as general skills, and more disciplinary knowledge. When adding the digital technology f*actor* explicitly, the perception is similar for the whole group of professionals but differs for engineers based on the kind of unique skills such as troubleshooting and systems analysis.

Learning for work by only focusing on one *actor* of the practice and possible connections to another material *actor* does not offer a complete understanding of learning for engineering practice as we have seen in the previous sections. By applying a practice-theory approach and using a network following the principles in *Actor*-Network Theory, it became clear that there is more involved in learning for work than just a discussion of individual job skills and knowledge. It moves beyond an individual learning understanding by showing that most learning for work happens predominantly at work where participatory practices are essential to work and deal with the unpredictable nature of this specific core engineering work practice. In particular, the non-human *actor* of digital technologies is key to *performing* the daily work and interacting between human and non-human takes place which are found in the reasoning capabilities.

Table 27.

Summary of the results of work practice 2 - Work

WORK	EP3 (Survey+ interview) Engineering	EP5 (Survey + interview) Technical	All 20 professionals (Survey)
Use of Digital	90%	90%	69%
Type of Digital	Simulation Modelling [circuit modelling] CAD Excel Specific discipline software	Mobile devices and apps Simulation MS Office	Mobile Devices and apps BIM CAD IOT Simulation
Data *performing*	Based on discipline software	Merging data from different project variables for planning purposes	-
Digital Simulations	Simulating a potential fault based on a worst-case scenario of the clients situation. The worst-case scenario is the starting point for safety purpose.	Forecasting how long a project will take based on data such as labour resources & Forecasting planning. Nothing simulated from activity point of view. More modelling the variables together	-
Decision making	All equipment and specifics for the design are based on the outcomes of the simulation	Based on data simulations for planning (resources and time)	-
Contextual (place)	Locally bound and depending on the project because work location is office on site. A big team and client are defining the practice	Locally bound and regulation impacted (community).	-
Change of work	Completely, changes found in capacity of professionals to automate tasks	Completely, core work has not changed but completion mode now digital (automated)	60% changed Completely, 40% Partially, 0% Not
Work complexity impact of Digital	Improved quality of work because it made other work tasks easier	Made work easier	-
Work advancement	Advanced	Advanced	Disrupted: 3.7% No effect on: 13.6% Advanced 82.7%

Note: This table shows the condensed insights from both 2 interviews and the 20 surveys for the research area of work
This table only shows the work practice of developing construction plans
Source data: 2018-2019 STWL-survey (de Munnik, 2020) & Analysis of the 2019 qualitative sociomaterial work and learning interviews with engineering professionals de Munnik, M. (2020).

Table 28.

Summary of the results of work practice 2 – Skills and Learning

SKILLS/ LEARNING	EP3 (Survey+ interview) Engineering	EP5 (Survey + interview) Technical	All 20 professionals (Survey)
Impact of digital	Digital technology itself has not changed	Changed the completion time of work and allows for on road doings	-
Enhanced human work skills	Completely, because the use gives time to think about other things to improve understandings and at the same time automating the human skills	Completely, supports in data capturing and storing and later retrieving when data must be compared for invoicing	65% Completely, 30% Partially, 5% Not
Replaced human skills	Partially, because it takes over some automatable tasks for which no longer human skills are required but also allows for the development of more advanced skills because time has become free	Not, because work tasks were automated which was not seen as replacement of human skills	40% Not, 55% Partially, 5% Completely
Core skills		General technical	Normal skills: reading, active listening, critical thinking, time management) Knowledge" economics, hr, production, engineering, construction)
Digital mastery, skills and learning	Yes, is learnt mostly during training or by using a ready model in-company. Telecommunications required, other three skills similar to normal skills package	Same as normal skills package. reading, problem solving, Programming, decision making, time management, financial res, mat res, pers res)	Skills: Reading (95%), writing (75%), Maths (75%), Time management (70%), Critical thinking (70%). Knowledge: Eng tech (80%), Building (75%), Design (70%), Maths (60%), English and Economics (55%)
Professional learning	Learning from a colleague at work is the dominant learning mode because both the theory as well as its practical application are used. Learning in school has provided the essential knowledge base and doing the work itself is also preferred for professional learning.	Studying in school (4 SK, 2 kn) Colleague at work (6 Sk, 2kn) Trial and error (3 Sk,1 kn) Intuition (1 Sk) Learning mostly from collegues in the form of a mentor that teaches the practical tricks to overcome unanticipated challenges.	Skills: study 21.2%, trial 18.9%, collegue 16.2%. Knowledge:study 44.5%, Collegue 15.4%, Trial 10.9%
Responsibility (digital)	Shared	Shared	

Note: This table shows the condensed insights from both 2 interviews and the 20 surveys for the research area of skills and learning
This table only shows the work practice of developing construction plans
Source data: 2018-2019 STWL-survey (de Munnik, 2020) & Analysis of the 2019 qualitative sociomaterial work and learning interviews with engineering professionals de Munnik, M. (2020).

The tables show that the understanding of the engineering work practice of *developing construction plans* improved by taking the interview insights into account. The practice of *developing construction plans* is relational and emergent. Both human and non-human *actors* exist in space and time and are thus embodied and relational. Collaborating with human *actors*, seemed often focusing on the collaboration between professionals with the same level and issues regarding power and professional judgement existed when was worked between different levels. The relation between human and non-human *actors* is mostly perceived positively if looking at the interview insights. Positive possibilities for future relational improvement were acknowledged. The results have shown that the practice of *developing construction plans* appeared to be more sociomaterial and more digitalized than the core engineering practice of preparing project reports. So far, the interviews and the ANT network have established that relationality between the *actors* in the practice network from the point of view of the human *actor* existed and thereby developing a focus on a relational direction from human *actor* to non-human *actor* and vice versa. It was shown that by applying a practice-theory and discussing the connections with the non-human *actors* in work it became visible during the interviews that the connection from human to non-human is apparent but is constructed in practice for each individual.

7.8 Chapter summary

This chapter presented the key insights that the participating engineering professionals working in the construction industry share their two core engineering work practices with both human and non-human *actors* such as digital *actors* who are *performing* activities in the work practice. Drawing on sociomaterial sensibilities which were explained in Chapter 4 being useful for considering human-digital relations, the stories of the engineering professionals have shown that professional learning for the select two core engineering work practices in a digital context must be understood as a learning location which emerges and changes in practice and is not being similar or stabilised across the cases in my study. Chapter 7 has thereby further strengthened the view from Chapter 6 that One size does not fit all applies to professional learning for the core engineering work practices of *preparing project reports* and *developing construction plans*.

The changes in work and requirements for the human professionals led to an understanding that learning was emerging in the work practice and changed in the *performing* of the work practice. At the same time, some stabilised learning mechanisms appeared such as learning from colleagues at work, using intuition and by trying things out in work to improve knowing-how to do the work.

Similar to the results in Chapter 6, this chapter illustrated that although all professionals experience changes in their work, the nature and the degree of these changes varied and that differences among the engineering professionals about the nature of the professional learning for the practice existed. The value of this chapter was that a further understanding of the nature of these relationships was developed as being shared professional responsibilities in the practice network that resulted in positive and negative effects on professionals based on basic and 'sophisticated' digital *actors*. The insights in this and the previous chapter together form a *thick* description to inform the answering of the research questions in this thesis which follows in the next chapter.

CHAPTER 8 -

ONE SIZE DOES NOT FIT ALL - SUMMARY OF STUDY ANALYSIS

8.1 Introduction

> "In times of change, learners inherit the earth, while the learned find themselves beautifully equipped to deal with a world that no longer exists." (Eric Hoffer)

I referred in Chapter 1 to the strength of applying research approaches allowing to explore both the learning which resides in the individual and the learning which resides in the practice, to focus on the daily work practices of engineering professionals in changing digital technology work contexts and inform learning for work discussions. In my analytical analysis of daily professional engineering work in an important economic industry, I illustrated that engineering practices can be understood as unique sociomaterial networks, characterised by *enactment*s heterogeneous *actors*. Individual capabilities to support the *enactment* but also knowing-in-practice emerged in the contextual dependent and continuous changing work practices. Learning opportunities developed, which enabled each professional human *actor* to deal with change in work and perform themselves into professional action. By being sociomaterial sensible, the effects of this contemporary form of research are that the research ends with thick descriptions which are on its own the contributions to the field of educational research. The application of *actor network theory* or another sociomaterial sensibility, such as the practice-theory, to research, do not favour interpretations of results since each analytically descriptive story on its own is a result which cannot be reduced and multiple ontologies exist. This is illustrated in the quote below:

> Theories usually try to explain why something happens, but *actor* network theory is descriptive rather than foundational in explanatory terms, which means that it is a disappointment for those seeking strong accounts. Instead it tells stories about "how" relations assemble or don't. As a form, one of several, of material semiotics, it is better understood as a toolkit for telling interesting stories about, and interfering in, those relations. More profoundly, it is a sensibility to the messy practices of relationality and materiality of the world. Along with this sensibility comes a wariness of the large-scale claims common in social theory: these usually seem too simple. (Law, 2009, pp. 141–142)

Nevertheless, I believe that since four of the case stories were presented in detail in Chapter 7 and data reduction is inevitable to keep the research focused, it is possible to extract what is similar and different across the cases with such different features and contexts and thereby moving to

focused insights. What follows in this section are the high-level insights of professional responsibility and learning resulting from working in a digital technology work context among the engineering professionals in this thesis.

In chapter 6, I have illustrated with the survey results that an argument about *one size does not fit* all applied to professional learning for this select group of engineering professionals. I showed the relevance of digital work technologies in professional *construction planning and project reporting work practices* and their impact upon the work practices of the participating engineering professionals working in the construction industry conceptualised as relations. While the case results showed relational similarities such as a change of work, relational variances across professional levels and countries were identified. Such as that engineering professionals in the South African work context did not experience the same degree of enhancement of human skills and technical professionals experienced more disruption of work and replacement of human skills as opposed to the other case locations. The same notion of variances across professional levels, countries, and between the core work practices also appeared relevant regarding individual skills and professional learning.

In Chapter 7, I explored how the participating engineering professionals were sharing their professional activities with different human and non-human *actors* in the two selected core engineering work practices. The stories of the professional engineering cases have shown that by considering sociomaterial sensibilities, professional learning for work in a digital context must be understood as a network in which digital technology is a constituting member of the practice and an *actor* that exerts power since professional work activities -acting's – are performed. The digital *performing*'s were found in exerting reasoning capabilities to execute, support, and improve human professional decision-making responsibilities. The professional engineering practice network assumed symmetrical relations between the different human and non-human *actors* in the practice and thereby showing that each professional *actor* was rebuilding the core engineering work practice through professional *performing*. The practice appeared at the same time as the learning location which emerged and changed in the *performing* of the practice, which was identified not being similar or really stabilised across the cases. Chapter 7 further strengthened the view from Chapter 6 that *One size does not fit all* applied to professional learning for the core engineering work practices of *preparing project reports* and *developing construction plans* of the participating engineering professionals.

In this chapter, I present the results of this study and connect them to the two research questions which were central in this thesis, after which I compare these insights of my work with other scholarly work. The differences and similarities to other scholars are contrasted and the move to a *translation* into a contribution appropriate insight is made. Finally, I extrapolate the main insights before the next chapter will focus more on my final recommendations and reflections for education. The discussion in this chapter includes the relevant insights based on both the survey and the interviews. The research questions or guidelines are first described, after which the section will discuss the results from the study which were translated into contribution appropriate insights.

8.2 Reconsidering learning as the effects of a relational practice network

Reconsidering practice as a relational network and professional learning as the effects of this heterogenous network was based on a reconceptualization of learning. Conceptualising how my theoretical understanding of professional learning for *preparing project reports* and *developing construction plans* work practices in relation to a digital work context may be understood as a unique network. In this network, digital technology is a constituting and *performing* member of the work practice, or also as a practice defining professional *actor*. This might change the conceptualisations of professional responsibilities and learning for engineering work practice. Professional learning understood as a continuous effect of the *performing* of heterogeneous *actors* (or *enactment*) corroborates Reich et al., (2015) understanding that learning opportunities develop when new sociocultural *actors* are part of the practice. I extend this and add that the learning opportunities develop when significant new sociomaterial *actors* perform themselves into action in the work practice. By focusing on the key insight and how it further supports, contrasts, or elaborates on current scholarly work, my exploration is guided by the two research questions:

RQ1: What do engineering professionals working in the construction industry perceive to be the key relationships between digital technology and their core professional work practices of *preparing project reports* and *developing construction plans*?

RQ2. How do digital technologies used in work, influence learning for professional responsibility of the engineering professionals working in the construction industry in the two selected core engineering work practices?

In exploring research question 1, I address the question by focusing on key professional responsibilities that were shared or taken up by the digital *actor* in the practice. I hereby draw on the

concepts of *performing* into action and shared or replaced professional responsibility. In exploring research question 2, I address the question by focusing on the learning insights that followed on the results of my study about engineering professionals' learning for the networked practices of p*reparing project reports* and *developing construction plans*. I do this by focusing on *enactment*s in the practice by drawing on a generalized symmetry common to sociomaterial theories such as Actor Network Theory. I further focus on professional practice networks and notions of learning, and how professionals deal with these unique situating and changing networked practices. In addition, I elaborate on research question 1 and explore the implications for learning for work.

The shared or replaced professional responsibilities were changing and thus shaping the core engineering work practices of *preparing project reports* and *developing construction plans* of each human professional. This may be termed as a unique sociomaterial networked relative "stability"(Scoles, 2017, p. 196), in which learning opportunities arise based on the significant *performing* of new sociomaterial *actors* in the practice. Moving forward to meaningful insights, the following sections position the high-level insights of this thesis by exemplifying what was found and explaining them with the scholarly literature where after they are addressed in more detail. The research questions, their backdrop and aim are first restated in sections 8.3 and 8.5.

8.3 Research question 1: Unique but strong human-digital professional relations

I showed in Chapter 1 that several reports and academic work had shown that digital technologies in work were having a significant impact on professional work. However, there was not enough detailed exploration to understand the relations to professional responsibility. I found a difference in the literature about a change of the work process that led to either a replacement or to human work or skill complementary. The direct requirements for professionals were that they had to possess the skills to work with the digital technologies, such as communication and knowledge management skills, possess their own core skills package, and were required to *translate* the digital technologies into their work practice. This was based on indications in the literature that a gap existed and detailed explorations about relations of digital technologies to professional responsibility were missing, an objective of the study was to explore this professional responsibility. Thereby drawing on practitioner perceptions of the core engineering work practices which was based on the practitioner account and identifying (*tracing*) the *performing* of *actors* in the practice. To explore what the relation with digital work technologies was. This *tracing* started from an assumption that digital technologies and engineering professionals were having relations which the study confirmed.

Therefore, in respect to the first research question, the study contributed insights about the role of digital technology in engineering professionals' working in the construction industry work practice and how it relates to their professionality or professional responsibility. The approach of sociomaterial sensibilities was adopted to view both human professionals and digital technologies as possible constituting and *performing actors* in the engineering work practices which allowed for *tracing* the relations between both human and non-human *actors.*

The main insight which I found connected to this first research question is that the shared or replaced professional engineering responsibilities led to the unique *rebuilding* of the core engineering work practice of each human professional and the practice was termed as a unique sociomaterial networked relative "stability"(Scoles, 2017, p. 196). The next section elaborates on this main insight that I found by addressing research question 1. Sociomaterial sensibilities have been useful for considering digital work technologies as participating members of the core engineering work practices or the so-called *actors*. This draws on the understanding of a generalized symmetry advocated for and subject to resistance of sociomaterial theories such as ANT which was discussed in Chapter 4.

8.4 Shared professional performing in unique changing work practices

What I found, based on my study results, was that human engineering professionals were sharing their professional activities with digital *actors*. A change of work was experienced among the survey participants and interview informants and different work activities were partially or fully shared with digital technologies. This was related to two change mechanisms, a positive and a negative impact in the sense that work became easier, and work became more difficult. The digital *actors* were *performing* themselves into professional action and completed different kinds of professional activities. I believed that I could therefore conceptualise them as *performing* digital *actors* which I then termed as digital professionals.

This study found that the engineering professionals experienced strong interactions with the digital technology members in their work practices since both survey and interview results established the existence of the strong relations. I found relations in the change of engineering professionals' work practice and on changing engineering professionals' work activities. The empirical work in this thesis discovered support for the use of more sophisticated digital technologies among engineering professionals in different countries. I traced and showed the specific *performing* of both human and non-human members of the engineering work practice from the insider account as per discussion in 4.4 of the engineering professionals themselves. These specific actions or *performing* were

understood as defining the relations between professionals and digital work technologies, which in turn were conceptualised as shared professional responsibilities. The human professional was as being found to be no longer the only one responsible for *performing* the professional work activities but shared with digital technologies termed as digital professionals. This means that they had an *enact*ing role in the *performing* of the engineering work practice, and this draws on understandings of a generalised symmetry used in sociomaterial theories. I reiterate the point that I made in Chapter 4, that this *enact*ing role or *generalised symmetry* resulting in professional agency of materiality does not assume that the digital is not different to humans. Although, they are different, drawing on post humanist perceptions and sociomaterial theories, means that no predefined power in society was thereby allocated to humans and no predefined social power was used.

What surprised me was that the engineering professionals were *performing* activities to make decisions for their work practice, whereby digital technologies performed various forms of basic and advanced reasoning activities. Notions of reasoning capabilities of digital technologies, such as those related to problem solving were found in previous scholarly (2.3). My insights corroborated the arguments that digital technology can complement workers to perform nonroutine problem solving (Autor et al., 2003, p. 1), and might extend the view that they are capable of limited mathematical reasoning (Elliott, 2017). The explanation for limited reasoning capabilities was that the advanced reasoning levels were not reached since they relied on complex knowledge systems in where a significant amount of rules formed the base which were learnt over time (Elliott, 2017). My study illustrated in relation to reasoning capabilities that Big Data appeared to be used for professional decision making which was partially related to the following professional work activities: making large amounts of information manageable, using historical data to inform decision making, using online data and transform, restructure and connect information. My study also illustrated that Simulations contributed to improved decision making by focusing on the following professional work activities: running worst-case work scenarios, running potential realistic work scenarios to see potential effects of a work solution, and simulating potential work futures to see possible outcomes from a technical implementation or design. It was in particular in the interview with engineering professional Ep7 that the *performing* of the digital *actor* was so advanced that I believed that they might have exceeded the notion of limited reasoning capabilities found in the work of Elliott (2017) in Chapter 2 and could rather be regarded as advanced reasoning capabilities.

The results in the empirical work about a perceived change of work in this study confirmed a possible association between digital technologies and professional responsibility found in discussions about the concepts of innovation and automation which were discussed in Chapter 3.

8.4.1 Increased work complexity – challenge and opportunity

The results in this study confirmed that not all the participating professionals were using advanced digital technologies and that country, professional level and work effect variances existed in my sample. The variance among different professional levels was also identified in the exploration in Chapters 1 and 2 of this thesis. The insight that digital technology made work more complex and easier for professionals at the same time was something I did not identify in other work before.

The results in my study about the use of the more advanced and sophisticated digital technologies such as Big data, BIM and Simulations, illustrated that work had become more complex for some of the higher level engineering professionals in my study. More was possible due to extended professional boundaries and professionals had to relearn how to do things. My insights corroborate the findings of Humburg and Velden (2017) who found a similar pattern of increased complexity of higher level professionals in the context of higher education graduates. The quote from the interview data in this thesis that best illustrates this view is the following quote from engineering professional 7:

> Wouldn't say it's made the work easier. It has made the more complex doable. So, it has not made my work easy. It actually made it more complex. And it just allows you to do more complex buildings. That is what it is. (Ep7)

The increased complexity for this professional led to both a challenge and an opportunity resulting from the interactions with the digital *actor* in the work practice. One such challenge was that increased coordination between *actors* was key and the *actors* had to be successfully mobilized depending on the process of similar interests (4.6) to achieve a stability in the practice which was the outcome of the work practice of *preparing project reports*. This stability is then understood as a *relative stability*. Reaching a common interest was challenging given the discussion in Chapter 1 about the diverse roles and complexity in the construction industry. This appeared relevant since this professional was dealing with a diversity of roles with different interests and increased complexity.

8.4.2 Reduced complexity of work – opportunity above challenge

The professionals at lower engineering levels in my study perceived that digital technologies made work less complex for them since digital technology performed certain professional tasks that were time consuming which resulted in improved task efficiency and reduced task time. This may be understood as a form of automation that brings challenges since the completion mode became digital (see 2.2)and work was replaced, however this was automation with a strong positive result resulting in professional opportunities.

Finally, although it appeared that survey and interview consensus was reached that digital technology reduced effort and time among technical and lower engineering levels, this was not the case for some engineering professionals in the higher levels. The interviews showed that some senior engineers and management believed that the work had become more complex, especially for higher levels. My insight that digital technology made work easier by a reduction of work time and effort for some engineering professionals corroborates with those of previous studies discussed in Chapter 2 by Susskind and Susskind (2017). Relating to the common discussions in economic research and following on discussions found in the skill-biased-technological change theory, I had expected that for lower levels of engineering professionals the relation with digital technology might be rather negatively perceived since digital technology was believed to being able taking over their automatable tasks. Surprisingly, this negative perception did not become apparent in my study among the lower engineering levels but there were some higher engineering levels expressing this view about a loss of professional agency for lower level engineering professionals. Interesting, however was that this assumed loss of professional agency among lower engineering levels was not experienced as such and their relation with digital technologies might rather be seen as a shared professional responsibility with denoting any positive or negative load regarding work replacement.

8.5 Research question 2: Shared professional responsibility

Several reports and academic work have shown that changes in professional responsibilities may have a significant impact on professional learning (Fenwick & Edwards, 2016). Little was done to provide detailed explanations about the implications for professional learning (Fenwick & Edwards, 2016) in this changing digital context, but studies were done on change connected to practice and learning (Hager, 2012). A prior study in engineering, Reich et al. (2015) found that non-human *actors* such as phones and laptops changed a specific site walk engineering practice based on *enactment* and *recording*. They also found that practices were *emergent* and *changed* in “the light of circumstances”(p. 18) and that learning opportunities arise within practices as they include new

human-*actors* and new objectives. They further confirmed an understanding following (Schatzki, 2012) about that when practices change, this is where learning happens. The focus on the importance of the place of learning is then acknowledged since learning is rooted in the practice. The quote below coming from their work, illustrates this view:

> Thus, learning can be fostered through exposure to new situations and challenges that prompt reappraisal of existing knowledge or actions or ways of thinking in consort with others. But these may not be 'large' changes — such as the introduction of new technology—learning may occur for example when an engineer 'works around' a specific problem on a site walk with an environmental scientist.(Reich et al., 2015, p. 19)

Based on indications in the literature to know more about relations between professional responsibilities and digital work technologies and the implications for professional learning, an objective of the study was to explore the connections to professional learning. Thereby, again, initially starting from an assumption that digital technologies and engineering professionals were having relations which were later in the study confirmed through the surveys and in the interviews.

The main insight which I found connected to this second research question is that the performing of digital technologies cause a change of the work practices of preparing project reports and developing construction plans but still allowing for learning in practice. Thereby corroborating the work of Reich et al. (2015) since in my study the learning continued despite significant changes related to digital technologies in work.

Following on the discussion about research question one in the previous section. Therefore, the next section elaborates on the insight which I found by addressing research question 2.

8.6 Rebuilding the work practice depends upon the professional *enactment* of *actors*

What I found as a second important high-level insight was that the core engineering work practices were contextually rebuild among both human and non-human members in the engineering work practice. Since they were each capable of *performing* themselves into actions in their own way or also understood as the ability to *enact* upon each other, and upon the practice. The concept of *enactment* was discussed in Chapter 4 and I found the three forms of *enactment* conceptualised by Orlikowski (2000) for technology useful to adapt to digital technology for discussing these insights as is shown in Table 29. The columns of the table indicate the major areas of relevance for each form of *enactment*, such as required knowledge and change of digital.

Table 29.

Forms of enactment and major areas of relevance

THE THREE FORMS OF ENACTMENT FOLLOWING (Orlikowski,2000)					
ENACTMENT	Interest in digital	Knowledge required for *enactment*	Institutional conditions	Change of practice process	Change of digital
Inertia	Low	Limited technical knowledge	Hierarchical, individual, competitive	No change of practice. keep same way of doings, limited use	No change of digital technology
Application*	Moderate to high	Moderate to high technical knowledge	Ranging from hierarchical to non-hierarchical, ranging from individual to collaborative, communal ranging from competitive to cooperative participative. Learner-oriented	Redefined work. Increased effectiveness in collaboration, communication, efficiency, cooperation, problem solving. For productivity and support	Adjustments in the technology
Change	High	Competent technical knowledge	Team-focused, cooperative, learning-oriented	Redefined work distribution, shift in collaboration, change in ways of learning. Change of practice and improvisation	Adaptations to the technology & Changes to the data. Transform

Note: This table shows the different forms of enactment adapted from the work of (Orlikowski, 2000)
** In Orlikowski's work the technology enactment form of application is divided into 4 subcategories with variances across the different columns. For clarity purpose this has not been used here.*

8.6.1 Enactment as inertia and application is most relevant.

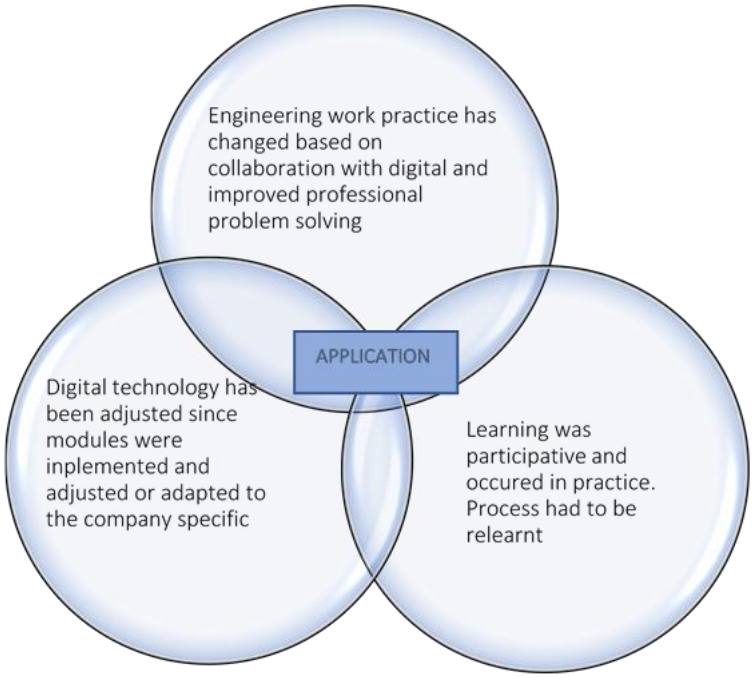
The first form of *inertia* became visible in my study since the human *actor* used digital technology in the practice for the same work performing, the digital technology itself had not changed and also the work practice remained the same. The empirical results in my study showed that this concept was relevant for all interview cases since certain work activities that were previously done in manual form were now executed in a digital form. This process of transferring professional work into a digital format in my work might also be understood as a broader notion of automation and adding to the insights in section 8.4. Then automation in other research was argued (Susskind & Susskind, 2017) to be often conceptualised as a simple concept. The simple concept does not include such notions as the conditions used in the different forms of *enactment* which are shown in the columns of Table 29. The second form of *enactment* was application which was found in my empirical work since the human professional used digital technology to improve the practice, refined the practice and applied some

minor changes to the digital technology. Some of the interview cases in my study showed this application form of *enactment* since they amended digital technology from its original developer form and added new models or connected other software, while at the same time this altogether streamlined and improved their work practice process.

Figure 35 illustrates the *application* form of *enactment* which appeared among the most (6) engineering professionals in the interviews in my study. The figure shows with the circles the three main areas of a change, namely, the practice process, a change of the digital technology, and the connections to learning. This aligns best with the concept of application following Orlikowski (2000) but then varies since the digital technology has received more significant adjustments by adding new models instead of slight changes to the program.

Figure 35.

The study found the enactment as application (based on Orlikowski,2000)



8.6.2 Enactment as change was rare.

The third form of *enactment* was *change*, which was found in one case of the empirical work in my study but notions about the areas being of relevance were identified in two other interviews (Ep5/Ep6). In the *enactment* form of *change*, the human *actor* used digital technology to improve the practice, changed the practice and also applied significant changes to the digital technology itself or

the "reprogramming of existing systems to include new features" (Wolff, 2018, p. 196). Only one of the empirical cases was identified to exemplify this notion of change in *enactment* since programming was used to change the digital technology which was then resulting as a change of the digital technology itself. At the same time, this *enactment* of change stretched the possibilities imaginable in work to the degree that it changed the professional work outcomes and processes of the professional concerned. To illustrate this, the story of the relevant professional Ep7 is described below.

In the third story, EP7, a professional in a medium-developed work context, learnt the daily work practice by *performing* the practice which was defined by a critical dose of self-motivation and the ability to upskill. Learning from a colleague in practice was highly relevant for this professional. Other human *actors* in his practice were changing his practice because he had to coordinate all the different human and non-human *actors*, such as drawings, specifications and regulations in where also digital technologies such as CAD, BIM, Simulations and computers where used. In my study, only human *actors* and laptops were similar to the ones found by Reich et al (2015) , although in the different engineering work practices of a site walk and design review meetings. The digital *actors* such as BIM and advanced Simulations were sharing a significant part of his professional responsibilities. In fact, most of his professional responsibilities were depending upon the *performing* of these particular digital *actors*. The digital *performing* was mainly found in the advanced reasoning capabilities, such as simulating the potential *performing* of the buildings in his practice. This was based on external materiality forces and the outcome was predicting which could be the results of these material interactions. From there on, this impacted the design, specifications and drawings of the building. The ultimate result from this shared professional responsibility was professional decision making which improved the quality of the work, improved the safety but also challenged the professional possibilities and deliveries further as opposed to when the professional was not sharing his professional responsibility with digital *actors*. In his interaction with the digital *actor*, he had to upskill himself to interact with them, where his programming skills, systems analysis and evaluation enabled him to *enact* upon the digital technology *actors* in his work practice. The professional viewed the digital technology *actor* as part of his professional nature which he argued was essential for his practice and expected to further arise in the future. This case story which was the only one coming close to a full *enactment* of *change* showed that this professional had indeed a high interest in digital technologies aligning the constructs in the first column of Table 29 and a rather positive attitude towards both learning and digital technologies. As a matter of fact, professional Ep7 satisfied all conditions for *enactment* of *change* which is illustrated by the table parts in green. This could be used to understand an ideal type of dealing with change as a professional with a positive attitude towards

digital work technologies, a positive attitude to and motivation for learning, a strong technical individual and shared knowledge base plus digital skills to *enact* upon them. The *mobilisation* has then been successful since the interest is similar and the translations are successful based on a common language or interest.

Table 30.

Enactment as change for professional Ep7

Ep7	Interest in digital	Knowledge required for *enactment*	Institutional conditions	Change of practice process	Change of digital
Enactment as Change	High	Competent technical knowledge	Team-focused, cooperative, learning-oriented	Redefined work distribution, shift in collaboration, change in ways of learning. Change of practice and improvisation	Adaptations to the technology & Changes to the data. Transform

Based on data: 2018-2019 STWL-survey (de Munnik, 2020) & Analysis of the 2019 qualitative sociomaterial work and learning interviews with engineering professionals (de Munnik, M, 2020).

8.6.3 Successful enactment upon actors.

Chapter 3 has explored that engineering practice required individual codified and tacit knowledge which features I found in my study and may make engineering professionals possibly more suitable to deal with change based on the knowledge required for *enactment*. This also, makes the engineering professionals more suitable for working with digital technologies which are based on the application of codified knowledge and is pattern-based as discussed in Chapter 3. The results in this study showed that engineering professionals required multi-disciplinary and multi-dimensional skills and codified and tacit knowledge to perform their work and to *enact* upon digital work technologies. The multidimensionality of engineering knowledge that was found in my study aligned with the knowledge framework of Figueiredo (2014, p. 20) which was discussed in Chapter 3. Codified knowledge such as physics and mathematics were found less important than general skills among my cases which finding does not align well with the insights from Wolff (2018,p.186) who argued that these two codified knowledge forms were the basis of most modern "engineering where machines and processes are present". The notion of Wolff (2018, p. 188) about the "horizontal knowledge structures" which may borrow concepts and rules from other disciplines such as sociology were argued to be aligned with the logic of ICTs. The reference to the non-transferability of these rules appeared relevant to the

results in my study since different technical computer skills as well as social skills were found among my cases.

The notion of non-transferability above is aligned with the concept of *translation* and professional *agency* discussed in Section 4.6. I believed that one should also investigate if workers having the abilities to fully translate digital technology in practice since the digital technologies form and change the practice network as do other *actors*. It was here when indeed the need to include both an individual skills discussion as well as a practice-based discussion appeared relevant which was elaborated on in Chapter 3. The data that helped to support this, in addition to the interviews, were the notions of digital technology mastery and digital technology change indicators – with focusing on the specific answers that digital technology had changed work and enhanced human skills- in the surveys and elaborations on the nature of these changes and *performing* of digital *actors* in the interviews. If engineering professionals had a lower digital mastery, as well as if they experienced digital technology as an interrupter and replacer of human skills, their interest was not aligned with that of the digital *actor*. The resulting possibility was that they would be less able to *enact* the full *translation* and then the digital technology was not able to fully *enact* as a professional *actor* in the core engineering work practice. Which in turn would lead to a slowdown of innovation and technology diffusion being relevant for low and medium-developed countries (See APPENDIX A – AN ECONOMIC PERSPECTIVE). The survey data of the digital technology skills and knowledge helped to support the identification of more codified and individual knowledge sources relevant for the engineering professionals in my study. These insights corroborates the notions from Goold and Devitt (2014, p. 261) in Chapter 3 of tacit and codified individual knowledge being important for engineering practice. The case story of Engineering professional 6 best exemplifies this notion of an improved possibility for *enactment* relying on individual knowledge.

The case story of EP6 showed that this engineering professional developed his practice in practice together with other human and non-human members such as simulation software that was used for reasoning which informed decision making and reduced time and effort. This reasoning capability of the digital professional was understood as the *application enactment* upon the practice and engineering professional. Other professional and material *actors* also *enact*ed upon the practice such as this professionals' co-workers and clients, construction site and calculators. At the same time, the professional indicated using specific engineering skills and knowledge which enabled him to work with the digital professional and thereby *enact*ing upon the engineering work practice. The potential digital *translation* in the practice could improve based on the notion that he would be able to do

more with digital technologies if he was able to program which could be supporting the transformation of this professional into the third form of *enactment*, that of *change*. As opposed to the engineering professional Ep7, this engineering professional did not satisfy all the conditions for *enactment* to be conceptualised as an *enactment* of *change*.

In addition to the digital *enactment* upon human professional and the *enactment* of human professional upon digital professional, the *enactment* between human and human professional is also key to the engineering work practices of *preparing project reports* and *developing construction plans*. Thus, different *actors* are *enact*ing upon one another and on the practice. This might mean that core engineering work practices are unique and contextually *rebuild* among both human and non-human members in the practice network and changes a focus on only the socio-cultural (Kaplan & Vinck, 2014) or on only an individual being important for the engineering practice network.

To conclude this section, the insight from my study about the shared responsibility with other *actors* and non-humans who *enact* upon one another and change and transform one another based on individual and practice based capabilities illustrates the work of Orlikowski (2000) with the different requirements for work, individuals and the technology leading to the three different forms of *enactment*. The insights that the engineering work practice was *rebuild* through *enactment*s between both human and non-human *actors* in the practice has implications for an understanding of professional responsibility since the engineering professional is no longer the only one responsible for the *performing* of the engineering work practice but individual skills and knowledge are impacting the *enactment* upon other *actors* in the practice which in turn increase or reduces their ability to perform themselves into meaningful professional action.

8.7 Knowing-how related to enactment relies on learning in practice

Successful *enactment* relies on knowing-how to which relies on successful *translation*s developed through work experience. This knowing-how was found in research before in discussions about tacit knowledge (3.5) and found to be the knowledge residing in individuals that was complicated to transfer in the context of engineering (Itabashi-Campbell & Gluesing, 2014, p. 142) and the significance of this for engineers in practice (Goold & Devitt, 2014, p. 261).

8.7.1 Knowing-how to work with digital and human actors.

Knowing-how to work with people refers to the social nature of the know-how and is a different form as when referred to knowing-how to work with digital technology which is illustrated in the quote below:

> Well we did some management courses, but I think where you learn the most is still on the job. I think the biggest thing about management is learning to deal with people. That doesn't time with the technology...it's all about being able to meet people and knowing how to approach. you change your approach with people (Ep6)

Learning to put digital technologies into practice happened through practice since a significant amount of selections were made for *while working* in the survey among the engineering professionals in the core engineering practices which counted for over two-thirds. This view was supported and elaborated on in the interviews and all professionals indicated that they learnt their practice in practice. Knowing-how to put digital technologies into practice appeared to rely on some basic knowing-how but mainly relied on trying things in practice. The learning that happened in the engineering professional work practice was based on learning for unpredictability, evolved in context among the different *actors* and with both human and nonhumans. Interactions with the digital professional relied on the relearning, the application of some form of knowledge foundation and building forward in practice by trying things out which can be understood as a mechanism of experience. While another notion relevant to experience, I believed, was the learning mode of trial and error, also understood as "trying things out" which is a work process located with learning as a by-product or non-intentional learning (Eraut, 2007, p. 409).The quote below illustrates this idea:

> We know the basics how it works but technology changes. We don't know how to do the new work and we do not get a proper answer with internet. So, we try it in the field. And normally; we know... we know the basics, that's why we apply it on that instrument. And when we try it, we know the results. If this is the result, we know this is going to happen in the next. (Ep1)

This mechanism of experience is the activity of learning based on activities in the workplace (Eraut, 2004b) and there does not have to be a specific learning purpose involved. This learning based on experience might be implicit or explicit and involving different principles as Eraut (2004b, p.250) states. The form of experience that becomes relevant to the results in this study is the professional experience understood as a physical activity in the work practice itself, or as the third principle of

practice referred to it, an embodiment and relationality between humans and non-humans (Hager et al., 2012).

8.7.2 Knowing-how to is sociomaterial.

The relations among people were apparent in the results in my study, such as the social relations that appeared by focusing on the notion of learning from other people. For instance, the mentoring that appeared relevant in some of the interviews. The following quote illustrates this:

> He has experience in this [] ...so he guided me in that. You know.... this is how the people are going to be (Ep5)

This incidence of social learning connected to experience might be understood as a form of a social learning process located in the work practice (Eraut, 2007) or a practice based learning opportunity and supports the idea that learning is *rebuild* in practice in a social-relational form. Connecting to the notion of materiality involved in the practice and which impacts learning, this learning practice was then conceptualised as a sociomaterial practice. The professional learning practice of engineering professionals in two selected core engineering work practices is then understood as a sociomaterial and relational learning practice that is rebuild in the network of the different *actors* in the engineering work practice.

The difference in the survey and in the interviews between technical and engineering professionals, of which the former had a slight preference for learning in school above while working, indicated that variances were at stake. Further research with a bigger sample to investigate if this distinction applies to more lower-level engineering professionals such as technicians, could be useful since *one size does not fit all* might also apply to professional engineering learning in a changing context for different professional levels. Nevertheless, a stronger relative stability was found in my work which was illustrated in Figure 36. The bubbles in the figure represent the stabilised learning principles for the engineering professionals in this study. Although variances and differences existed among the engineering professionals in this study, the common principles of learning how to do the work and working with other *actors*, learning through experience and the significance of the work practice may be understood as accepted stabilisations of the learning practice. These accepted stabilisations may be understood as a sociomaterial notion of stabilisation which was discussed in section 4.6.

Figure 36.

Dominant learning mechanisms for the engineering professionals in this study



8.7.3 The practice as learning place, the case of the engineering work practice

The core engineering work practices were thus professional learning places for engineering professionals. This may be understood as a support of work-based learning and learning by *performing* the practice which focuses on the importance of exposure and participating in practice and experience. The variances in my study between school as the place of learning for knowledge and the workplace as the place of learning for skills may support the notion that academic knowledge as a foundation can be developed during school-based education and the application into practice happens in the workplace which support the arguments for work-based learning with a focus on real engineering work experience to make this development relevant and contextual.

The survey results led to defining the dominant learning modes which were found in both participatory as well as acquisition forms of learning. These views were supported by analysing the case story exemplars and it appeared that the theoretical work part was learnt in school or university and the practical work knowledge and applications were learnt more through participatory modes of learning, which further supported an argument for learning through practice and work-based learning. Learning from more experienced professionals is something that all participating engineers agreed upon. Learning through experience seemed the dominant mode in the engineering work

practices which were understood to be more on the participatory side of learning and mechanisms such as trial and error were commonly used. The quote for engineering professional EP6 illustrates this:

> I think it's more for the practical on the job side kind of knowledge (Ep6)

This practical kind of "job side" knowledge referred to above points to the notion of knowing-in-practice which is situated and a practical achievement (Gherardi, 2009, p. 117) or practical know-how (Gamble, 2003). Know-how was apparent in some of the interviews and supports a view that the practice of the engineering professionals in this study demands knowing-in-practice. Knowledge of this group of engineering professionals can then be seen as the knowledge which is embedded in the practice (Hislop et al., 2018, p. 31), a practical exposure which relies on experience and knowing-how which corroborates the findings of Gamble (2016b, 2016a) in a context of craft work as experience being important for technical work. It also aligns with the insights from Itabashi-Campbell and Gluesing (2014), that engineering knowledge can also be viewed as "ways of knowing" relying on what to do and how or based on the concept of Phronesis of Aristotle when solving engineering problems. The latter was then further supported relevant for engineering work in the context of the build environment (Flyvbjerg et al., 2012; Kirkeby & Flyvbjerg, 2011).

8.8 Chapter summary

In this chapter, I explored the relevance of my empirical work which was described in Chapter 6 and 7 in connection to the research questions and the existing literature. In relation to the focus on engineering professionals' relationships with digital work technologies and implications for work learning, I came to the following two main insights which I believed were key to my work:

Insight 1: Understanding human-digital interactions in professional *construction planning and project reporting* engineering work practices as unique shared professional engineering responsibilities which rely on the *performing* of heterogenous actors who rebuild the engineering work practice altogether.

Digital technologies which I termed as digital professionals were complementing engineering professionals in the work practices which created professional opportunities and challenges. Challenges were found in the increased complexity of work and advanced possibilities for the work outcomes. Opportunities were found in reduced complexity and time reduction of professional effort which created possibilities for increased quality. The human professional was regarded to be no longer the only one responsible for completing the professional work activities - or performing - and the digital technologies could now be named as digital professionals. This means that they had an *enacting* role in the performing of the engineering work practices, and this draws on understandings of a *generalised symmetry* used in sociomaterial theories. Digital technologies in the empirical work of this thesis were found to complement human professionals in the reasoning execution of their daily work. But multiple variances among different professional levels and locations existed. The relation was dependent on the *enactment* of human professional upon digital

In exploring research question 1, I have illustrated that the shared or replaced professional engineering responsibilities led to the unique rebuilding of the core engineering work practice of each human professional which I term as an unique sociomaterial networked relative "stability"(Scoles, 2017, p. 196). The human and nonhuman *actors* in the practice were sharing their professional existence and negotiating their professional *performing* which relied on individual, social and practice-based forms of knowledge, which resulted in changing core engineering work practices.

This is helpful since it shows that learning for professional engineering practice may be termed as a **unique networked relative stability**. With unique, I mean the aspect which aligns with the insight found in Chapters 6 and 7 about a *one size does not fit all* notion since variances and differences were found between the engineering professionals practice and practice network. Network in this case relates to the different human and non-human members constituting and rebuilding the practice in which they perform themselves into action. The practice was then

understood as a stability for a while to reach the common goal, objective or outcome of the work such as in my engineering practice cases, the outcome of the final project report or construction plan in which different *enactment*s between *actors* defined this relative stability and was subjected to change which was making the stability relative.

In exploring research question 2, I have illustrated that one size does not fit all applied to learning for work, but some stabilised features might be relevant for all professionals.

Insight 2: Understanding the learning for professional *construction planning and project reporting* engineering work practices in relation to human-digital interactions may be termed as a unique socio-material networked relative stability in which learning opportunities arise based on the significant performances of new digital actors.

The human and non-human actors in the practice were translating their professional existence and negotiating their professional *performing*'s which relied on individual and practice-based forms of knowledge, which resulted in changing core engineering work practices. Engineering professionals working in the construction industry in the empirical work of this thesis learnt their engineering work practice through experience, by learning modes such as trial-and-error and learning how to do the practice. But the professionals required both individual skills as well as skills found in the relational sociomaterial practice network. Digital technologies were found to require new demands of human professionals and focused on re-learning how-to work with digital technologies as well as re-learning how-to do their work practice. By being sensitive to the unique engineering practice networks constituting of multiple human and non-human actors, the design and development of the educational practices related to this professional engineering practice could address more than individual or social learning opportunities but extend to socio-material practice learning opportunities. By being sensitive to the continuous change which may result in learning opportunities in practice, learning programs can neither be fully stabilised nor homogenous but must be addressing contextual variances, such as country variances, disciplinary variances, but also professional level variances, and allow for individual and practice-based learning opportunities.

I discuss the recommendations and effects of these insights in the next chapter.

CHAPTER 9 -
CONCLUDING CHAPTER

> "Every theory is correct in its own world, but the problem is that the theory may not make contact with this world." (W.E.Deming)

9.1 Introduction

The previous chapter has shown the discussion of insights of my study in the light of the main research questions in this thesis. Chapter 8 has contributed to an improved understanding about the relation between human *actor* and digital *actor* which was understood as a shared professional responsibility. This shared professional responsibility meant that both *actors performed* professional activities in which their individual and practice-based skill sets allowed them to *enact* upon each other and *perform* themselves into action in the engineering practice. This has led me to understand these insights as, human-digital interactions in *professional planning and reporting engineering practice* as unique shared professional engineering responsibilities which rely on the *performing* of heterogenous *actors* who restructure the engineering work practice.

Chapter 8 has also shown that the practice acts as a professional learning place in which the human professional interacts with the engineering work practice and other professionals to learn how to be a professional member of *professional planning and reporting engineering practice*. Such as through mechanisms of experience and learning from colleagues or by continuously keeping own skills up to date. The human and non-human *actors* in the practice were translating their professional actions and negotiating their professional *performing* which relied on individual and practice-based forms of knowledge, which resulted in a change of *professional planning and reporting engineering practice*. This has led me to conceptualise these insights as, understanding the learning practice for professional planning and reporting engineering practice in relation to human-digital interactions as a unique sociomaterial networked relative stability in which learning opportunities arise based on the significant performances of new sociomaterial *actors*.

Education could support this diversity and similarity by addressing unique flexible work practice based learning opportunities which are sensitive to recognize the unique networked relative stability of the professional practice which is subjected to continuous change in fast changing environments, such as the environment of the construction industry. By being sensitive to the unique

engineering practice networks constituting of multiple human and non-human *actors*, the design and development of these educational practices could address more than individual learning opportunities. By being sensitive to the continuous change which may result in learning opportunities in practice, learning programs can neither be fully stabilised nor homogenous. This means that the learning opportunities must addressing contextual variances, such as country variances and industry, but also professional level variances. Furthermore, the learning opportunities should ideally allow for individual adapted learning trajectories since each individual also exerts force on the networked practice based on individual performing. The learning practice for professional engineering practice can then be conceptualised as a unique sociomaterial networked relative stability.

I draw on these insights to position that perhaps engineering learning practices in education require reconsidering and might need to be restructured to acknowledge the unique sociomaterial networked relative stability nature of engineering practice and learning. My educational suggestion is that learning for work in the context of digital technological change should happen through participatory work practices.

In this chapter, I summarise which insights I can contribute with my thesis to educational research. I start with the research problem and main question and present how the thesis was developed in the Chapters guided by the two research questions. I continue with the key insights which were developed in my exploration and carry on with offering suggestions for leaning practice, for both engineering work practice as well as research practice fitting in the field of workplace learning and educational preparation for work. I conclude the chapter to offer modest recommendations for future research, address the main limitations of this thesis and reflect on my own development during the path of the PhD program.

9.2 How the thesis' chapters contributed to the research problem

In Chapter 1, I introduced this thesis by addressing that research and industry had indicated that the world of work was changing and was influencing workplaces and workers. Education was often blamed for not keeping up with developments in the industry and individual professionals not able to keep pace with the changing nature of work. One major driver associated with these changes was the digital technology driver and previous researchers in education indicated that not enough detailed information was available about the implications of digital technologies for professional practice and learning. One suggestion was that it could change how professionals developed their professional knowledge to stay or become a professional. Two different views on the development of

professionals appeared, namely the learning residing in the individual and that residing in the practice. I then identified to focus on the engineering professionals' working in the construction industry for three reasons: since the construction industry was important for the economy, the nature of the industry was diverse and the state of innovation in the industry was argued to be in a developing state. I therefore selected to focus on the two daily work practice of the engineering professionals in the construction industry to provide a contribution. This contribution was to improve understandings about implications for professional practice and learning attributed to working with digital technologies and I positioned my work in the field of workplace learning research.

It appeared in work place learning research that work conceptualised as professional practice could be connected to learning and change and subsequent the learning theories that were fitting contemporary descriptions of human and digital technology relations were found in the sociomaterial theories. One of those theories identified was the practice-theory and has led me to work with sociomaterial approaches and I draw on the 5 principles of practice which linked learning, change and professional practice (Hager et al., 2012). The research areas of interest were then identified to be work, learning and change related to the digital technologies used in work. First, since the practice framework argued that there was more than knowledge residing in individuals, I identified that both an individual professionals' account as well as a view on the core engineering work practice could develop more insights as opposed to only focusing on the practice. This two-folded focus has then led me to focus on individual work skills and knowledge residing in the individual but also to focus on the notions of knowing as a collective thing and connected to the material and social world or also termed knowing-in-practice. Second, my focus moved between the professional and the engineering work practice in which I identified two specific core daily engineering work practices. The work practices of *preparing project reports* and *developing construction plans*. The major focus relied on the understanding that a practice was sociomaterial and relational and evolved in practice, but each member of this practice was contributing their individual share to the practice. Third, I identified *Actor Network Theory* approaches as a second stream of sociomaterial theories to be suitable for tracing relations between professionals and digital technologies in their work practice based on the notions of a *generalised symmetry* and the inclusion of materiality, but also based on the opportunity to connect to notions of learning.

Professional learning was then understood to be something residing in individuals which relied on knowledge and skills but also something which was embedded in a practice. I identified the need to know more about, where or when professionals learnt, such as work-based or in school. The

consequence was that I only focused on the individual learning modes connected to work for the individual account and the learning connected to the practice for the practice account. In the former, I was asking the participants directly how they learnt their work knowledge and skills, and in the latter I was tracing notions of learning connected to the practice, based on the interviews with the engineering professionals. The notions of learning were thus gathered by directly asking the professionals themselves and not through observations.

In chapter 2, I focused on understanding the possible relations between human and digital in work practices by focusing on a diversity of research found in academic, industry and economic literature. The reason for selecting this broad diversity of literature was since digital technologies were developing so fast that academic research could not always keep up with this pace and industry research could expose a different view based on the different agenda's. The discussions in the economic research were identified based on one major theory found in the skills-mismatch discussion which was that of skills-biased technological change. Although this theory was often used in discussions about wages, I identified the theory relevant for my exploration since it related workers activities conceptualised as tasks to skills. The two major areas for the relations were then presented, namely the replacement of work and skills and the complementary of work and skills. The different digital capabilities appeared relevant to show were digital technologies could complement humans in work. Based on the literature, those were found in different categories such as reasoning and physical capabilities. I showed in the chapter that a connection between skills and digital technology could result in a demand for higher educated people. This was based on three features: they could have the skills that were required to better deal with change, had an ability to upgrade their skills in times of change, and their work was less likely to be automated.

The concepts of automation and innovation (Susskind & Susskind, 2017) were presented based on the debates which focused on the likelihood of skills being replaced or advanced by automation, the development of new working practices due to innovative digitalisation, and the advancement of skills. I continued with exploring briefly which change of workers was required to deal with these digital technologies and found that they required a general knowledge base, codified and tacit forms of knowledge to work effectively with digital technologies. I then explored the specific digital technologies found in the construction industry and discussed three digital technologies and their use more specifically, BIM, Digital analytics/Big data, and CAD. Of which all three were found to be interconnected software with multiple possibilities for use in professional engineering practice. The major point which I made in this chapter was to show how digital technologies used in work could

connect to human professionals and in which ways they could impact those in the construction industry. The need was then identified in this chapter to know more about the skill profile of the engineering professionals who had to work with these digital technologies.

In chapter 3, I explored the nature of the engineering professionals and their learning based on the literature found in workplace learning research and engineering research. I presented the exploration based on the two understandings of the learning residing in the individual and the learning residing in the practice. The two major insights from this chapter were that the key changes in workplace learning as a field of professional learning were found in the place of learning - education or work-based- and the unit of learning - individual or practice with each their own understandings about learning and implications for professional learning. The changes in the unit of learning were also associated with a shift in paradigms, from learning as acquisition and learning as participation. These paradigms were understood as a change in the metaphors of learning and learning in the former was understood as an individual happening and a 'thing', wherein knowledge was acquired and the context less relevant; in the latter it was seen as something that happens both individual and collectively with different *actors* through participation in work-related activities, such as through participation in professional practice. This notion of two major understandings of the unit of learning motivated me to foreground the focus on both the individual and the practice for my study as well as to include a focus on the place of learning.

The specific discussion about engineering knowledge and skills in this chapter focused on the concepts of explicit knowledge, tacit knowledge and knowing-how or knowing-in-practice in which general, tacit and engineering specific knowledge appeared relevant for engineering professionals. I showed that research on skills had identified the need to measure skills explicitly and I found that the task-based model (Autor et al., 2003), which was used for analysing changes in task composition and demand for shifts in skills, was a useful framework for this measurement. Based on the arguments that this framework could be used for identifying which tasks could be executed by technologies (Acemoglu & Restrepo, 2018, p. 2) but also the potential to connect to skills motivated me to select this approach. The arguments that knowledge and skills were connected motivated me to keep a focus on both (Engineering Council South Africa, 2018; Layton, 1974). I briefly explored the digital technology skills which would appear useful for workers to work with digital technologies and found both general and technical skills appearing in the literature, such as programming and data handling skills. Based on the different conceptualisations of skills, I adopted an understanding that skills could reside in the individual but also residing in work. Drawing on engineering practice literature, I found

that researchers adopted contemporary approaches and sociomaterial theories appeared relevant from an educational research tradition (Fenwick & Edwards, 2010; Reich et al., 2015; Rooney et al., 2014). Engineering practice was then understood as more than problem solving but a social problem solving practice (Heywood, 2016; Williams et al., 2014) that happened together with different human *actors*. Specific engineering skills and knowledge were found in four major areas for which I selected to draw on the engineering dimension framework (Figueiredo, 2014, p. 20). The four major areas of dimensions found in theory/practice and people/matter were all identified as relevant for engineering professionals in general. This urged me to adopt this framework for guiding me in researching the different knowledge aspects of engineering work and investigate the individual professional learning base.

The purpose of professional learning to become a better proficient practitioner changed my focus on professional learning in where concepts such as experience and practical experience appeared relevant for engineering professionals (Heywood, 2016; Williams et al., 2014). To understand learning in the context of change which was associated with more informal modes of learning such as work-based learning, a shift to focus more on those found in learning as participation was required and I identified the concepts of learning modes to identify source and place of learning relevant for this purpose (Felstead et al., 2005). The arguments that the concepts of acquisition/participation were limited and could change the perception of reality of engineering as heterogenous others (Rooney et al.,2014, p. 267) motivated me to keep the focus on the possible network of engineering practice open of which I identified the 5 principles of practice useful to guide me in this task. The three major shifts in theories of professional learning were found to have shifted from behaviouristic and cognitive theories, to socio-cultural to sociomaterial theories of which the last allowed for an acknowledgement that materiality had constituting power in the work practice and learning was then seen as an ongoing process subjected to change. This urged me to select sociomaterial theories as useful for the theoretical backdrop of my study of which the practice-theory was one.

In chapter 4, I presented that the gap in empirical research remained and in practice-based research, not explicitly the connection to the digital was made. Based on the insights from chapter 3 in selecting sociomaterial theories as appropriate to acknowledge the role of digital technologies, I invited the Practice-Theory and Actor Network Theory as the important components of my research toolbox. The toolbox approach was identified to invite and exclude who were joining the task of my investigation. The possible existence of multiple ontologies was regarded as relevant aligned with a

post-humanist view. This allowed to invite materiality in the exploration of a social matter such as learning. Both sociomaterial theories assumed a relevant role of digital technologies as a part of the work practice and the developments over time showed them as most relevant for me to move beyond seeing materiality as a separate object. This thesis adopted the framework of Hager et al. (2012) for theorising about practice, and it shifted the need to focus on the practice as a whole by using the five proposed principles, which stated that a practice was: (1) knowing in practice, (2) sociomaterial phenomenon, (3) embodied and relational, (4) change and evolve in social contexts, and (5) emergent.

The doings, activities or so-called *performing* as concepts were identified to make the actions of both human and non-human members of the engineering practice visible. The argument that the practice should be researched from an insider practitioner approach was recognized and the engineering professionals their perceptions selected as the way to follow this insider approach. Some researchers in the field argued that a practice-theory application could only be done by physically observing the practice as a researcher (Nicolini, 2012), but others in education did advocate for survey and interview accounts with practitioners to inform the practice view (Mulcahy, 2013). It is the latter form of practitioner focus that I selected to draw on. Another relevance identified in the exploration in this chapter was that a practice had to be studied analytically and descriptive and explorative forms of research appeared relevant which should end in modest and thick data descriptions instead of strong interpretations and a specific vocabulary.

My thesis' research toolbox included the second sociomaterial theoretical sensibility, that of *Actor* Network Theory which was identified useful for education:

> *Actor*-network theory traces the ways in which human and non-human elements are *enacted* as they become assembled into collectives of activity. These complex, interwoven 'networks' can spread across space and time, and produce policies, knowledge and practices. ANT-inspired studies trace the micro-interactions through which diverse elements or 'actants' are performed into being: how they come together - and manage to ***hold*** together - in 'networks' that can act. These networks produce force and other effects: knowledge, identities, rules, routines, behaviours, new technologies and instruments, regulatory regimes, reforms, illnesses and so forth. No anterior distinctions such as 'human being' or social 'structure' are recognized – everything is performed into existence. Callon (1991) explains that the nature of all agents and what they do depends entirely on the morphology of relations in which they are interwoven. (Fenwick, 2010, p. 120)

The theory appeared to have strong relevance for investigating relations between the so-called different *actors* in the practice and their *performing* or actions. The major point of ANT that no predefined agency should be allocated appeared relevant to me to acknowledge a possible social

impact of digital technologies in the work practice. I presented the major oppositions against the theory which were found in predefining models, colonizing objects, and allocating agency to materiality and explored the ways to reduce these oppositions. Another point in this chapter was that I explored that the nature of our way of thinking could resist dealing with change and limiting a view to include materiality with more defining agency into our world. I showed that the more sophisticated forms of digital technologies relying on Artificial Intelligence would further change this believe in the future and urged me to consider material agency as a possibility. The symmetry assumed that no individual member would have power outside the practice, but their performing would lead to their active constituting of the practice. The relation between the *actors* was seen as the defining power and changed my view on the possible relations between professionals and digital technologies. The concepts describing this process were *performing*, *enactment*, and *translation*. *Enactment* was selected useful to describe how the different areas of change, knowledge and attitude would lead to the successful performing of the digital technology in the engineering work practice. I further drew on the concepts of *translation, mobilisation*, professional responsibility, *generalised symmetry, and professional agency.* Using these theoretical resources, I showed that, by focusing on the practice and including digital technologies as possible significant *actors*, this could open up a thick description of engineering practice and learning. The adoption of the two sociomaterial theories and the different extensions in my work could be regarded as a sociomaterial sensibility since no predefined models, structures or a fixed toolbox were used (see 4.2) and those appropriate to task were invited.

In chapter 5, I focused on the guiding methodological framework for conducting the study in this thesis which led to the selection of the empirical case study in which I traced the relations between human-digital in the work practice of the engineering professionals. I conducted participant view case studies of which the sequential approaches aligned with the two different views on learning which was residing in the individual and in the practice. The data that I gathered were 41 quantitative surveys and 7 semi-structured qualitative interviews of which the former followed the approaches seen from learning residing in the individual and the latter included a broader view on learning residing in the practice by following the 5 principles of the practice theory. Since I was interested in tracing the human-digital relations, I adopted the visual strength of *Actor* Network Theory to map the engineering practice network of the participants in the second part of my study. By tracing these relations, I approached each practice member as a potential *actor* in *performing* professional work activities. In the thick case story descriptions resulting from drawing on the 5 principles of practice as the guiding framework, I searched for connections to learning and individual performing which would enable workers to *enact* upon each other. Following the practice seen from the perceptions of the

engineering professionals themselves also allowed me to go back and focus on the individual engineering professionals. These thick case story descriptions and post-human stories as my analysis were then mainly resulting in the thick work practice descriptions in Chapter 7. In Chapter 6, I followed the research areas of concern to analyse the survey results which were no thick descriptions but starting assemblages for continued exploration in subsequent chapters. In Chapter 8, I discussed my study insights and connected them to the existing literature to develop useful implications which could led to form modest educational suggestions. In the following sections of this chapter, I present the syntheses of the discussion of these insights and make suggestions for learning for practice and research.

9.3 Key insights and educational recommendations

In this thesis, by drawing on sociomaterial theoretical approaches framing this research and given the discussions in chapters 6, 7 and 8, I believe that this thesis has contributed insights to the main question driving this work: **What is the role of digital technology in engineering professionals' working in the construction industry work practice and how does it relate to their professional responsibility and learning? –** The response of my thesis to this question is two-folded, whereby the insight from the first leads to the second:

Understanding human-digital interactions in *construction planning and project reporting engineering work practice* as unique shared professional engineering responsibilities which rely on the *performing* of heterogenous actors in the practice network who rebuild the engineering work practices.

Understanding the learning for professional *construction planning and project reporting engineering work practice* in relation to human-digital interactions as a unique socio-material networked relative stability in which learning opportunities develop based on the change caused by the significant performing of heterogenous actors.

By contributing and answering this question, this thesis has developed an understanding about the learning of this select group of engineering professionals working in a changed digitalised construction industry workplace. I draw on these insights to position that engineering learning practices in education require reconsidering and might need rebuilding to acknowledge the unique sociomaterial networked relative stability nature of engineering practice and learning. My educational point is that:

Since the unique sociomaterial relative stability of the network of the *construction planning and project reporting engineering work practice*s, stabilised and set educational curriculum are increasingly challenged and thus a relative stability. Participation in real professional engineering work practice is modestly suggested to cater for this understanding about learning for professional practice. Although learning for engineering work in the context of digital technological change should happen through participatory (real) work practices, the individual knowledge base should receive attention which may or may not be addressed in academic education or embedded in programs directly connected to engineering work practice. *engineering work practice*s, stabilised and set educational curriculum are increasingly challenged and thus a relative stability. Participation in real professional engineering work practice is modestly suggested to cater for this understanding about learning for professional practice. Although learning for engineering work in the context of digital technological change should happen through participatory (real) work practices, the individual knowledge base should receive attention which may or may not be addressed in academic education or embedded in programs directly connected to engineering work practice.

My empirical results illustrated that the selected engineering professionals in my sample were experiencing a highly digital influenced work context which resulted in different connections with their professional responsibility. Different relations were found such as for instance, some higher professional levels were experiencing an advancement and increased complexity of their work while lower engineering levels were more often seeing replacement of tasks that were automated. Another relation was found in the skills required to work with digital technologies and I believe that the multidisciplinary nature of engineering skills and knowledge was an advantage working with digital technologies. I also illustrated that a lack of mastering these skills had consequences for the sharing of professional responsibility with digital technologies. The concepts of *Inertia, application and change* (Orlikowski, 2000) were used to make the different areas of this change visible and thereby the focus on both the learning residing in the individual and in the practice remained.

The study insights urged me to believe that the core engineering work practices were found to be contextually *rebuilt* among *heterogenous actors* in the practice. *Enactment* with digital technologies happened in three forms in where the notions of change in work and change in digital technology appeared relevant for my cases. Which had an impact on professional responsibility but also that change is inherent to engineering work practice and formed among its active participating members. This has possible implications for how we think about professional learning. Professional

engineering learning may be seen as a contextualized sociomaterial event in which change is inevitable and happens in the interactions between its participating and *performing* members. Professional engineering learning, therefore, might need to reconsider that dealing with change, such as change associated with the participation of digital technology *actors*, is part of the nature of practice. So are relations with other human members and non-human members which results in an understanding that all need to be part when considering professional engineering learning and all are inherent practice change drivers.

My conceptual suggestion is that engineering professional learning must be understood as learning as participating in relational practices of a changing sociomaterial network in which I elaborated on the concept "stability" found by Scoles (2017) and added relative to make it a relative stability. My argument was that professional engineering learning in a changing digital context could be conceptualised as a unique sociomaterial networked practice which is composed of, and *rebuild heterogenous actors*, including the digital professionals. A performative focus showed that both the human and non-human *actors* may display professional agency in the practice which I found as the ability to perform professional responsibilities. This understanding removes a focus on individual professionals only, as being responsible for professional engineering practice. It supports the view that a practice is more than individual capabilities or skills of human professionals, but it rather focuses on the network of an engineering practice. In the network, not one individual only needs to possess all the knowledge or skills, but this is rather a constitute of the network and one another can therefore supplement each other.

The nature of the practice and therefore the requirements of its participating members – the professionals – depends on how the *actors enact* or perform upon each other and on the engineering work practice. This *enactment* can be understood as something that is situational, contextual and personalised. The point that I make now is that *not one size fits all*, not for engineering practice and not for engineering learning. Every single individual engineering professional *rebuild*s the practice in the specific network of the practice that is formed, so do other human *actors* and non-human *actors*, and every engineering practice is the *enactment* of every single *actor* that constitutes the work practice. Therefore, the practice and learning can be regarded as unique. The suggestion I offer is that the consequences for understanding professional engineering learning are that learning in practice is essential and learning for professional engineering work must move beyond: the 'acquisition' of codified knowledge units, the development of only individual skills, not facilitating the development of

tacit skills, the use of a stabilised curriculum due to the emergent and changing nature of the practice, and move beyond any strict dissociation between education and work.

The discussion about that tacit knowledge seemed to reside in the opposite of the systematic, codified or explicit knowledge. Although, the discussion in Chapter 3 had shown that most engineering academic education and the guidelines from the professional bodies seemed to focus on the codified knowledge, the study in the thesis had also shown that more tacit forms of knowledge and knowledge residing in practice are important for engineering professionals. Goold and Devitt (2014, p. 263) argued that although there is "seldom a unique right answer in engineering'', engineers prefer the use of objective and scientific knowledge to find "a one hundred percent right answer". In engineering education, "tacit knowledge is neglected at the expense of "objective'' knowledge" (Goold & Devitt, 2014, p. 263). This ambiguity of what is offered in academic education and promoted among professional bodies versus what is required for practice has implications for the connections between education and work and the needs for professional learning. Chapter 3 showed that when knowledge is embodied in people in the form of tacit knowledge it means that its transfer to another entity or cultural context was complicated and once again support the notion for unique network practice arrangements in learning for professional engineering work. Chapter 8 had indeed shown that the know-how became visible among the engineering professionals in my study but at the same time their codified knowledge was important to their practice and working with digital technology.

While I acknowledge that professional learning resides in the *enactment* of the actors in the practice network, I also suggest that individual professional learning can contribute to the development of the individual human capabilities to *enact* upon the digital professional. Therefore, professional education might consider addressing a real work practice account but also develop the individual skills that are associated with these digital *enactment*s such as allowing to develop general skills, tacit skills, and more technical skills such as programming and troubleshooting relying on a strong technical and general knowledge base.

I believe that education could address this participatory engineering work learning by providing a dual system which is existing in higher education in The Netherlands per discussion in Chapter 3.6. The system consisting of both academic schooling and real professional work is on itself not novel. However, the literature on professional engineering learning discussed in Chapter 3 revealed that the design of real professional engineering work practice with all its responsibilities and

actors is not commonly found in education programs targeting professional engineering learning (Engineering Council South Africa, 2018; Heywood, 2016; Reich et al., 2015).

9.4 Contributions

Despite the exploratory nature, this thesis adds to an understanding of the relation between digital technologies used in work and engineering professionals working in the construction industry. This thesis makes three original contributions to the knowledge about professional engineering learning for work in a changing digital technology context.

The first contribution that this thesis makes is providing an detailed exploration about the connections between engineering professionals and digital work technologies in which it contributes an empirical account of the two core practices in engineering of *preparing project reports and developing construction plans* to contribute to the gap that little detailed exploration in work was done (Fenwick & Edwards, 2016). The human-digital interactions in *professional planning and reporting engineering work practice* can now be understood as unique shared professional engineering responsibilities which rely on the *performing* of heterogenous human and non-*actors* who significant *perform* themselves into action and *rebuild* the engineering work practice. Digital technologies in the empirical work of this thesis were found to complement human professionals in the reasoning execution of their daily work and automated work activities such as through *performing* calculations, simulating worst-case scenarios, material ordering notifications, which were not seen as work replacing since the available professional time was spend to improve other aspects of the work practice. Digital technologies also changed the demands for the individual and collective skill sets, such as that more technical and general skills were required to *enact* upon digital technologies to benefit the work practice but also increased coordination between *actors* was required. The insights were not for all engineering professionals the same since several variances among different professional levels and locations appeared. For instance, Ep7 showed an advanced notion of *enactment* with the use of far more 'sophisticated' digital technologies and required increased coordination with his human counterparts but at the same time experienced digital technologies as part of the 'nature' of his engineering work practice. This contribution of the detailed exploration is important since this improves understandings about the intersection of human and material world and provides an account that goes beyond common views that digital technology only replaces people at work. At the same time suggest that contextual and individual differences are significant considerations when addressing learning for work in changing contexts.

As a sub-contribution of the first, my thesis contributes an novel empirical account of a detailed exploration of different engineering disciplines and professional levels of engineering work by focusing on two select but significant core engineering work practices of *preparing project reports* and *developing construction plans* which would benefit the understandings about what is going on at work and could be potentially used to inform comparisons with data from both ISCO-08 and O*Net on which a diversity of other country systems rely and which are used to inform the development of educational programs. Directly related to this is that my thesis also contributes explicitly to our understanding about the use of specific digital technologies in the work of engineering professionals working in the construction industry and has established strong connections between digital technologies in work and engineering professionals.

The second contribution that this thesis makes is to conceptual knowledge by providing an account of the notion of professional learning for becoming or staying a member of engineering practice that is understood as something that occurs in a sociomaterial networked practice that changes, termed as relative stability and for which learning should ideally include a work practice-based account in education. This is important since education and professional learning programs should consider including a practice-based account in their program. However, this must not be confused with the situation of a form of apprenticeship in where no meaningful and professional work is performed which cannot be regarded as a practice-based account and a full learning opportunity. Taken together, these contributions do not support educational solutions or professional learning programs in which only a theoretical account or individual learning is dominant.

Third, my thesis makes a contribution with the novel methodological considerations of this thesis. This thesis has adopted a view of a mix between two units of learning. Namely, for the former, the notion was on the individual professional and their skills and learning for work, while the latter showed an inclusive and relational network of a practice in where both the human and non-human *enact*ed on the practice and could receive similar agency and power. A second methodological f*actor* to mention is that this thesis has used a new quantitative research instrument, the survey that connected the different components in a practice which allowed for a continued qualitative analysis of both the individual and the practice.

Fourth and finally, my thesis makes a modest recent contribution to the body of knowledge of studies applying sociomaterial sensibilities by providing an empirical account of the ways how materials (digital technology) are taking part in a specific social-interaction (professional engineering

work) which remained under examined. In doing this, this thesis strengthen the argument made by Reich et al. (2015) to show that a practice-theory is useful for understanding engineers' professional learning, specifically in a changing digital technology context and adds that extending the practice-theory with other sociomaterial sensibilities (Actor Network Theory) is useful for focusing on complex engineering work practices and a complex material actor.

9.5 Suggestions for future research

My suggestions for future research on engineering professionals' work practice is the need to focus more on the sociomaterial nature of daily core engineering work and the network of different *actors enact*ing upon each other. This would be a fruitful focus area for further work on professional practice and any form of a changing nature of work. Future research should above all, consider changes to various aspects of the study design. For example, to facilitate for both a practice as well as an individual perspective on learning, these should be dismantled in the study design to do right to both. Whereas the use of the practice view might benefit from direct researcher led observations, this is less the case for research aligned with the learning that resides in the individual since it is difficult to observe something what is assumed as residing inside. Another research opportunity is that any research about digital technological change should be repeated again in short intervals of a few years only. Especially, considering the fact that the development of digital technologies develops so quickly, this also requires more frequent and flexible approaches towards research. The use of prefixed frameworks for the research is therefore not recommended because it will not facilitate for an understanding if change occurs. Therefore, I would argue for the relevance of sociomaterial theory approaches to research since they allow for the required flexibility to adapt the research framework to change as well as allowing for emerging directions in the research.

Future research design should include, where possible a larger sample with both workers in non-technical and technical impacted environments to include a comparison and better understand the impact of this context. The measurement of the specific group of professionals should be expanded to a professional group that does not necessarily entail the use of all four different kind of skills and knowledge areas such as that the engineering professionals in this study appeared to have . This might help to understand if it is indeed a feature of the nature of individual engineering skills which makes this specific group of engineering professionals better able to adapt to change (*enactment* ability) and subsequent educational policy can be informed with these. I believe that the variety of engineering professionals' professionality contributes to adaptability to work with digital technologies and adapt to change which can be the objective for future research since their profile

could then be used to inform research in other disciplines and inform educational policy development for designing educational programs.

A suggestion directly relating to the limited empirical results offered in this thesis are that the exemplar insights into the different and unique skill, knowledge and digital technology profiles of the engineering professionals could be potentially used to investigate similarity and difference against the databases that feed into job descriptions such as O*Net and ISCO-08 and also to explore difference and similarity against existing educational programs in the specific engineering disciplines in this study. Which relate directly to a potential use of my insights for industry when designing training programs to keep engineering professionals up to date and considering including the notions of the network, and exposure in real work practice.

9.6 Limitations of this thesis

The limitation is that this thesis has offered no strict and final interpretations which can be perceived as a lack of a final contribution of the thesis as regarded in realist and positivist informed research. The ontological position and the empirical nature of the study led to an analytical analysis of the results which in turn contributed to the exploratory and descriptive nature of providing the thick case descriptions and insights guided by the research questions. This approach fits well in the sociomaterial theories with a post-humanist view of placing humans “not above materials (as the creator or user) but among materials”(Sørensen, 2009, p. 2). In researching learning for work, over-generalisation is a concern as positivist-oriented research appears to neglect the contextual effects of the study and in this thesis would neglect the undefined power of the sociomaterial theories and the contextual variations among engineering professionals.

A limitation based on the focus on the engineering practice is that I did not observe the core engineering work practices of the participating engineering professionals in the second part of the study directly. This would indeed be regarded as a major limitation seen from the traditions commonly found in researching practice and if I would have used a fixed research approach of grounded theory and ethnography. Nevertheless, I would indeed regard a lack of observation as a limitation since more detailed information would benefit the current study and responder bias would potentially reduce.

Another limitation is that the insights of my thesis cannot be extrapolated to all engineering professionals and must be interpreted with caution since the empirical work was based on a limited

and diverse sample of engineering professionals working in the construction industry and generalisation is not possible. Therefore, it would be good to have a larger sample divided equally among work context and professional level. It may also be useful to see the specific engineering disciplines separately.

Although the focus in this study was on professionals' own perceptions, the study could be improved by adding different perceptions of other stakeholders in the field such as those of different other *actors* since among different groups, different interests and views can exist. This would on turn also remove the potential bias of participants resulting from using self-reported measures.

9.7 Concluding remark.

To conclude this thesis, this journey has added both to my professional and personal development in significant ways and I give an elaborated reflection on my own learning in APPENDIX N- AUTOBIOGRAPHICAL REFLECTION – PERSONAL DEVELOPMENT. The journey has led me to sociomaterial theories and although these introduced their own complexities to the research, I am also convinced that they opened powerful doors. I hope that I have done right to the principle of generalized symmetry by being careful with my vocabulary and using the same for both human and non-human actors in the work practices. I have also tried to prevent myself from making final judgments about the positions of the engineering professionals but treat them as multiple ontologies. Lastly, tracing the actors in the engineering practice was to a lesser extent done by tracing without predefined structures or fixed roles (Callon, 1984, p. 17) but I sincerely hope to get the opportunity in the future to conduct academic research, where this is possible.

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APPENDICES

APPENDIX A – AN ECONOMIC PERSPECTIVE

CHANGING WORK AND THE IMPACTS ON PROFESSIONALS – AN ECONOMIC PERSPECTIVE

The Endogenous Technology hypothesis related education to technological change because "the stock of human capital determined the rate of growth" (Romer, 1990, p. 71). For example, the "famous Pin Factory story of Adam Smith" where workers became more productive with the division of specialised work tasks instead of executing all tasks was endogenous. Then the Directed Technical Change hypothesis indicates that technological progress is endogenous and the "nature of technology" adapts to the circumstances (Acemoglu et al., 2003, p. 26). Subsequently, this process feeds into the demand for educated workers and thus triggers implications for the relationship between demand and supply of skills (Acemoglu et al., 2003).

This helped me to believe that in the case of developing countries, the nature of technology would indeed adapt to the circumstances of the workers, even when there were fewer skills available. If this occurs, it could slow down the development of developing countries and less educated individuals. In that case, it could be seen in reviewing indicators on the adoption and diffusion of digital technologies in those specific countries because then they should indicate a slow-down on the diffusion of technology innovation in that particular country which would support the 1966 hypothesis of Nelson & Phelps, that "educated people make good innovators so that education speeds up the process of technological diffusion" (Nelson & Phelps, 1966, p. 70) and a supporting argument for the need of education. Some researchers indeed indicate that the level and years of formal education in developing countries is unrelated to the increase in worker productivity (Colander & Gamber, 2002, p. 159) and growth. For example, an increase in education in African countries accompanied a slowdown in growth in that part of the world (Acemoglu et al., 2003, p. 17) and thus the relation between years of schooling and productivity, whereby the growth was not yet visible. However, a relation between technological progress and growth rates is more likely to exist and is more in line with the expanded Solow Growth Theory.

Another theory is the New Growth Theory. This includes an extended understanding of technology's role in growth with the focus on the 'Endogenous Theory' where capital, labour, human capital and an index of the level of technology were the inputs in the model (Romer, 1990, p. 78). In this model of Romer, labour was measured by skills and human capital by notions of formal education and completed on-the-job training activities. According to (Heckman, 2006, p. 4), the New Growth Theory focused on the determinants of technology, such as capital labour with measurements on research

and development expenditures, technology use in the process, with both methods and tools. It also included a focus on the environment as the diffusion of technology is different around the globe. An interesting explanation for the technology diffusion differences across the globe is that "there tends to be significant learning by doing in the technology process" (Colander & Gamber, 2002, p. 165) and with repetition one becomes proficient and productive. This indicated a valid economically focused point to include measurements of where workers have learnt their skills and the place where they have done this. Higher-skilled workers were less likely to be replaced. New technologies were believed to be demanding more skilled (e.g. more educated) workers above lower-skilled workers (Vivarelli, 2013). This is in line with the original explanation given by Nelson and Phelps in 1966 (1966, p. 69) that educated workers are better able to adapt to disequilibrium. According to Nelson & Phelps, education improves abilities to "receive, decode, and understand information, and that information processing and interpretation are important for performing or learning to perform many jobs" (Nelson & Phelps, 1966, p. 69). An increase in the demand for higher-educated workers is indeed seen as a proof of the SBTC theory and shows a possible evidence base for a correlation between computer technologies and education (Autor et al., 2003, p. 1279). The same research also showed that this is, despite criticism that other research failed to answer, exactly what technologies do that causes this effect or that without decent jobs the theory is not applicable.

The above indicated that the return of education seemed to be, in general, valid, but there had to be "quality" jobs (Keep, 2012) and also the technologies available, to process this educational return (Acemoglu et al., 2003, p. 17). Even in the case that the technologies were available in developing countries and the features of the SBTC apparent (Vivarelli, 2013b, p. 79), if the workers were not able to work with these technologies, which may be associated with a lack of skills, a loss of efficiency and a slower further diffusion of the technologies would be the result . The result may be that the inequality among countries regarding computer and human resources will likely continue.

Although the impact of technological change on growth could be explained by both the exogenous and endogenous theory, the exogenous theory was not relating technological change within the process but saw it as an external factor. The two directions of the SBTC-theory and its accompanying hypothesis of an exogenous and endogenous understanding were relevant to the current thesis to understand the relations between technology and skills perceived from an economic perspective. A continued discussion about the difference in SBTC direction is beyond what is required to understand that direct connections between professional work, digital technology and educational implications possibly existed. Therefore, the work in this thesis acknowledges the possible

symmetrical directions between higher-skilled workers and technology but locates the work in line with the technology – higher-skilled discussion - exogenous SBTC hypothesis - wherein two discussions were key. Namely, the first one about task replacement and the second one about task complementing. Both were found to have direct consequences for the individual professional working in the engineering field and were thus relevant for this thesis.

It is here that the discussion about changing skill demands became apparent. This so-called technological change in industries was believed to cause disconnections between what was required in work and what was being taught. It may have generated new skill demands for professionals which was understood in broader terms as can be seen in the quote below:

> By changing the nature and range of tasks graduates are expected to fulfil in today's economy, these trends generate new and intensify traditional skill demands, which we summarize as professional expertise, flexibility, innovation and knowledge management, mobilization of human resources, international orientation, and entrepreneurship. (Humburg & Velden, 2017, p. 201)

If there is indeed a disconnection between the industry requirements and the way workers are educated, this was often referred to as a *skills-mismatch*. Thus, one of the underlying causes of a perceived skills-mismatch between education and work was the digital technology driver. This influenced the workplace in some interrelated areas: the work process, the division of work, and the deployment of specific tasks in the workplace. This possibly caused a disconnection between what workers were being educated to do, and what was necessary for work. We live in an era where almost all processes are becoming computerised, and it has become the new norm for workers to be able to either adapt to these systems or experience disadvantages in securing and keeping jobs. Therefore, the concept is not only relevant for new graduates and schooling systems but also workers in existing jobs and their professional learning. Therefore, the focus of this thesis is on professional learning to both become and to stay a professional. However, it must be noted that the view on Human Resource practices with the goal to define workers' performance is not the objective nor direction of this thesis

APPENDIX B-GUIDING QUESTIONS RESEARCH

GUIDING QUESTIONS EMPIRICAL WORK

The areas of concern of the empirical work and the research sub-question:

EQ1: What do engineers perceive to be the key relationships between digital technology and their core practices?

EQ1.1 What is the work-task composition of engineering professionals?

EQ1.2 What technologies are being used in the work of engineering professionals and how important are they to conduct the work?

EQ1.3. What is the effect of digital technologies in work on the work-practice of engineering professionals– now and in the future?

EQ1.4. What is the share of automation/innovation in work-tasks?

The second area of concern of the empirical work was to analyse the work-skills, the work-skills required to be a member of the work-practice.

EQ2. What are engineers' perceptions about how they learn these core practices?

EQ2.1 What is the work knowledge-skill composition of the engineering professional?

EQ2.2. What is the correlation between specific work skills and knowledge?

EQ2.3. What specific forms of knowledge-skills are most relevant? (E.g., theory, practice, generic, non-routine, cognitive, engineering- specific etc.)

EQ2.4. What skills and knowledge are required to work with digital technologies?

EQ2.5. Is there any skills group significant to do the work while working with digital technologies?

EQ2.6. Do all professionals master working with the digital technologies used in their work?

EQ2.7 What is the general composition of learning for work for the engineering professional?

EQ2.8 Is a correlation apparent between learning skills and knowledge in a more digital impacted work -task?

EQ3.0 What is the primary form of learning for the engineering professional?

EQ3.1 Is work-based training becoming increasingly important for the engineering professional?

EQ3.2 Where have engineering professionals learnt their digital technology skills?

APPENDIX C-STWL DESIGN ELABORATION

AN ELABORATION ON THE DESIGN OF THE STWL-SURVEY

Existing surveys were not linking the research concepts involved in the specific selected context and I therefore designed a new survey that was used in empirical phase 1. I shall hereafter refer to this specific survey instrument as ***STWL-Survey - Skills, Technology and Learning for Work Survey***. The need to develop a new survey instrument was identified because existing instruments were not work-practice specific and newer and construction industry specific digital technologies were not used. Therefore, the *STWL-survey* used the task and skills categories coming from the US occupational information network 'O*Net' (Handel, 2016b; O*Net, n.d.). The O*Net database finds its origin in the Dictionary of Occupational Titles (DOT) and has, like other survey instruments, its strengths and weaknesses. For example, weaknesses in the repetition of questions, the difficulty of questions on the design side and questions regarding the completion of the results side and strengths to capture explicit skills measures (Handel, 2016b).

Other adult skills- and work-surveys existed, such as the STAMP and PIAAC. These were assessed but were not fulfilling all the design requirements per this study requirements. For instance, the workplace skills, technology, and management practices survey- STAMP claimed to be using explicit scaling and specific questions that leave no room for misinterpretation looked promising, but the way digital technology features were used, were not aligned with the required measurements necessary for this study (Handel, 2016a). Another example assessed in the light of this study was the adult skills-survey - PIAAC which is conducted by the OECD and directly measures the skills of respondents in work and personal life contexts. The survey measures these skills by letting people solve the cognitive questions and tasks on a computer. The PIAAC instrument is explicit, displays positive features such as measuring the skills directly, and is not self-reported. Less positive features such as the survey being expensive to conduct, time-consuming plus not fulfilling the criteria as set made the instrument not relevant for this study. The survey section on 'problem solving in technology-rich environments' seemed especially appropriate for measuring skills and digital technologies for this study. However, the fact that the survey used notions of traditional digital technologies, such as the use of spreadsheets, the use of the web and e-mail, meant that it did not fit the criteria for digital technologies in the construction industry (see Chapter 2) used in my study. On another note, direct measures of people's cognitive abilities by having them conduct 'exam' like

surveys do not indicate the required work-skills but only workers' personal attributes and competences. The above three examples (1) O*Net, (2) PIAAC, and (3) STAMP were just three of the many skills surveys that exist, and I am not claiming that I analysed them all before deciding to design my own survey. However, the three surveys addressed above were the most important since they include measurements focused on computer technologies or digital technologies in the context of measuring skills for work.

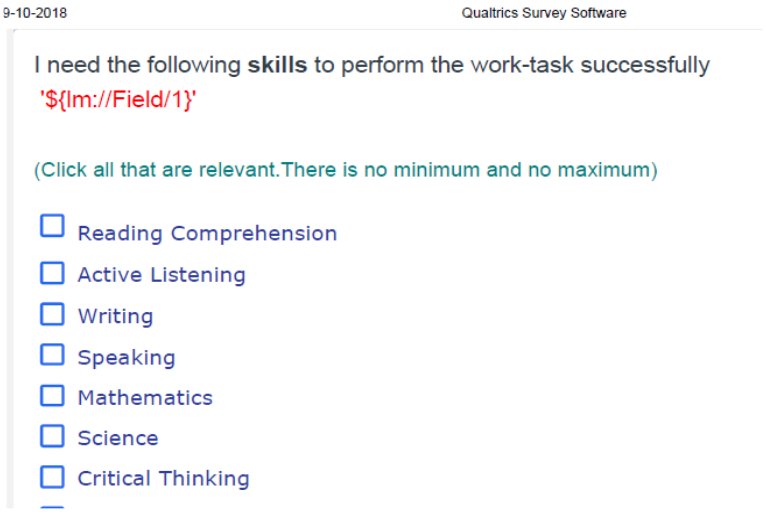
I developed the *STWL-survey* in QSR *Qualtrics* by using: (1) the skills and knowledge categories of the O*Net Surveys, (2) the task categories of the O*Net 2018 report for civil engineering technicians(O*Net, 2018), supplemented with 4 open categories, (3) categories of digital technologies relevant for construction found in the literature in Chapter 2, and (4) the learning for work categories from researchers Felstead et al. (2005a) supplemented with more recent learning modes that. The skills, knowledge, tasks, digital technology and learning were then connected by using connecting functions and basic programming in the Qualtrics survey software.

Three important approaches to the survey's design are important to further elaborate on. The first approach to designing the survey was that the O*Net categories were feeding into the survey. Although the O*net database covered work activities for multiple hundreds of occupations I selected only a broad and central one in the engineering professional group as a guideline for the design.I selected the 15 O*Net work tasks from the 2018 report for civil engineering technicians and supplemented with flexible 'other'… categories. The reason for selecting the work tasks of an occupation in the mid-level range and adding flexible categories was to facilitate for both higher- and lower-level workers among the group of engineering professionals.

One of the main considerations that fuelled the decision to use only the names of the skills and knowledge categories from the O*Net survey, and not their original importance and level indications, was that both the level and importance questions of skills were extremely highly correlated and it would have been unnecessary to use both. Another reason was that the questions were understood as difficult to interpret (Handel, 2016b). I was aware that only using the names of the skills could be too abstract for the respondents. There is also the danger of semantic confusions about using single word work terminology and that there is a possibility for own interpretations among participants. Nonetheless, I decided to accept this risk for the benefit of having a simple minimalistic design which I show below. In the figure, the skills question in the *STWL*-survey is depicted and by using a plain and simple design that takes up minimal space for respondents to view,

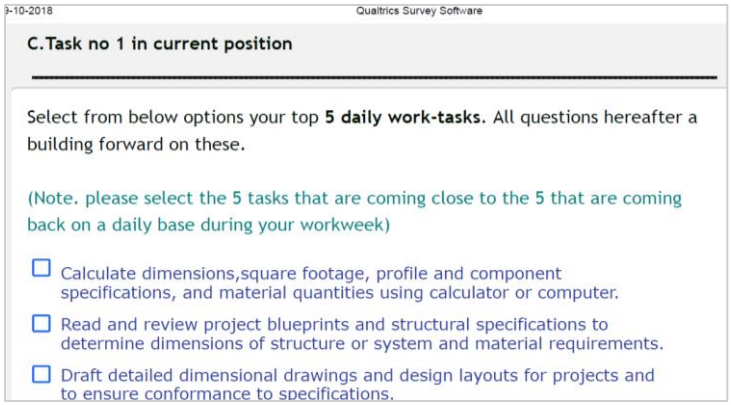
it allowed me to include the option for respondents to select multiple skills at the same time. I am aware of the design being perhaps too simplistic, but I had to make choices regarding the survey design as I had to include more categories to allow for the variety of required data on my different identified areas of concern.

Figure 37. Interview excerpt skills section



The second approach to the design of the survey was that I selected the task-based approach as this was argued to be a relevant framework for analysing job skill requirements at the occupational level (Autor et al., 2003; Autor & Handel, 2013) and it "links the tasks and activities that workers perform on the job to the skills needed to carry out these activities" (Autor & Handel, 2013, p. 60). By selecting the task-based approach, I had to link work-skills to the daily work tasks of workers and as such, I required a design in which I could include and link both. See in the figure below for the extract from the survey instrument that were guiding the core work-practice selections.

Figure 38. Survey section with daily work tasks



The third approach to the design of the survey was that the learning modes used in the survey were partially based on the categories of Felstead et al. (2005b). For example, "while studying for a qualification" and "using trial and error" came directly from their research. *While taking an online course* is an example of a category that I added based on the perception that these extend the recent possibilities for understanding where learning takes place.

The survey connections that were made between the areas of concern are shown indicates the relationships between the three areas of concern in the survey and illustrates that work tasks are directly related both to work-skills and work-knowledge as well as to digital technology indicators. The 35 skill categories, 33 knowledge categories and 19 digital technology indicators were linked to a specific work-task, according to the task-based approach discussed in Section 4.7. A survey instrument was thus designed that was specifically equipped for the purpose of my study. In addition to different demographic and social attributes, such as gender, educational attainment, and work experience, the specific variables that were aligned with the areas of concern were included in the questions as is shown in APPENDIX D-STWL-SURVEY. Furthermore, Table 31 also shows that the *STWL*-survey consisted of different types of questions, such as closed questions, multiple-choice, ranking, and limited open-ended questions. Different types of response options and scales were used to maximize answering options since this was associated with greater participant accuracy "views on a given subject" (Wilkinson & Birmingham, 2003, p. 15).

Figure 39.STWL survey pathways. Source: Personal collection

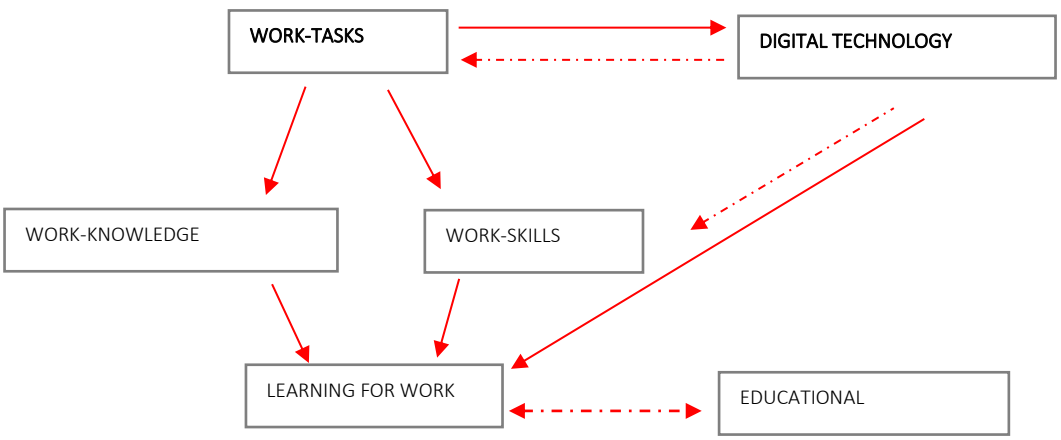


Table 31.

Survey topical content

SECTION	STWL-WORKERS SURVEY – TOPICAL CONTENT	RESEARCH CONCERN
a	General Bio/Basic information *Name of company where respondent works, Gender of respondent, Age Bracket of respondent, Nationality of respondent, Residency of respondent, Duration of Residency of respondent* *Completed levels of school of respondent, Time after school completion of respondent*	Socio-economic/ Demographic
b	Work bio/Work specific information *Construction industry experience of respondent, Job title of respondent, experience in current job of respondent, Levels of school in engineering of respondent, Work-based training*	Socio-economic/ Demographic
c	Work-Tasks *Selected top 5 daily work-tasks of respondent*	Work-Tasks
d	Digital Technology Digital technology used by respondent in work-tasks| %use of digital technology used by respondent in work-task Belief of respondent that digital technology changed work-task 2013-2018 Belief of respondent that digital technology will change work-task 2018-2023 Belief of respondent that digital technology replaced need for human skills in work-task Belief of respondent that digital technology enhanced human skills in work-task 'Skills' used by respondent to perform work-task successfully	Automation/Innovation Human Skills Skills Knowledge
e	Learning for work Dominant way of learning the skills for work of the respondent Dominant way of learning the knowledge for work of the	Learning Mode Learning Mode
f	Working with digital technologies and learning for work Mastery of working with digital technologies of respondent, respondent's perception if digital technology has changed the task, learning to work with digital technology of respondent 10 most important skills of respondent to work with digital technologies 10 most important knowledge fields of respondents to work with digital technologies	Learning Mode Professionalism Work-skills Work-knowledge

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The survey was piloted before the final design was finalised to test and remove errors (Wilkinson & Birmingham, 2003, p. 19). Therefore, the survey was tested as follows: Firstly, I tested the survey informally among engineering professionals working in the construction industry, including feedback received during an informal meeting with a civil engineering professor specialising in digital construction of a major American university in the United Arab Emirates. The received feedback was incorporated into the survey. Secondly, I used the 'generate responses' option in the Qualtrics software to evaluate if the intended responses were generating the required data and made amendments to the survey. Thirdly, I used the 'evaluate survey' option within the Qualtrics software to indicate whether the survey's length, language and design were within professional boundaries associated with high response rates. I made some language improvements but mainly length improvements. Lastly, I used the feedback from supervisors and peers to optimise the final design of the survey and conducted an additional round of informal testing. I used the same informal testers as in the first test. This could be improved by testing among a new sample of informal testers but unfortunately, the access to engineering professionals was scarce and I was not willing to sacrifice any of the potential research participants.

APPENDIX D-STWL-SURVEY

Introduction

Dear Participant,

Thank you for participating in my Survey!

This Survey is part of my PhD thesis for the program of Doctor of Education at the University of the Witwatersrand in Johannesburg.

The questions in this survey are about tasks in your daily work, the use of skills and knowledge to perform these tasks, and the use of digital technology.

The completion of the survey will take approximately 20 minutes.

All your responses will be handled with care for privacy and anonymity. That means that the data of this survey will not be connected to your name in writing up the results, and your name or personal details will not reflect in my thesis or other academic publications. Furthermore, your individual data connected to your name will not be shared with your company either.

The data of this survey will be used for academic purposes, including my thesis, journal articles, and conference proceedings.

Please, make sure that you understand the question before answering. **There are no right or wrong answers, it is your opinion which is important.**

If you have any feedback or questions regarding this study, please feel free to contact me at 00971 55 955 2879 or at marloesdemunnik@gmail.com

Thank you in advance for your participation and you acknowledge the above information about your participation and give herewith consent to participate in the research.

Marloes de Munnik
PhD Candidate Education and Labour
Research Protocol Number 2018ECE009D

Validation

Have you read the information in the introduction about your privacy, anonymity, and participation and do you give **consent to participate**?

Yes ○ No ○

A. General Bio

What is the name of the **company** where you work?

(Please note: No company names or any of your details will be shared with others. I just need to know the company for the background of your workplace)

Please, select in the dropdown menu your country of **Nationality**.

Please, select in the dropdown menu your **country of residence**.

For how long have you been residing in your current **country of residence**?

- ○ Less than 1 year
- ○ 1 to 5 years
- ○ 6 to 10 years
- ○ 10+ years

Select ALL levels of **school (academic)** that you have completed

- ☐ Less than high school/secondary
- ☐ High school/secondary/matric diploma
- ☐ Some college, but no degree
- ☐ 2-year college degree
- ☐ 4-year college degree
- ☐ Graduate-level degree/ Bachelor
- ☐ Post-Graduate-Level degree/Master degree and above

How long ago have you completed your highest level of **(academic) schooling**?

- ○ Less than 1 year
- ○ At least 1 year but less than 3 years
- ○ At least 3 years but less than 5 years
- ○ At least 5 years but less than 10 years
- ○ 10 years or more

B. Work Bio

About how many years have you been working in the **construction industry**?

- ○ Less than 1 year
- ○ At least 1 year but less than 3 years
- ○ At least 3 years but less than 5 years
- ○ At least 5 years but less than 10 years
- ○ 10 years or more

What is your **job title?**

About how many years have you been working in your **current job**?

- ○ Less than 1 year
- ○ At least 1 year but less than 3 years
- ○ At least 3 years but less than 5 years
- ○ At least 5 years but less than 10 years
- ○ More than 10 years

Please, select all (academic) schooling in **engineering** you may have done.

- ☐ Less than high school/secondary
- ☐ High school/secondary
- ☐ Some college/vocational
- ☐ 2-year college
- ☐ 4-year college
- ☐ Graduate-level/bachelor
- ☐ Post-graduate level/master and above
- ☐ No (academic) schooling linked to engineering

Have you done any work-based training- how many days in total during the last 5 years?

(Work-based training is **NOT** the same as schooling but professional Training at Work, organised by the company or professional body:

'a structured programme of learning where work skills are practised, or experienced, in a work-like environment')

- ○ Yes, I have done work-based training... **days**
- ○ No

C.Task no 1 in current position

Select from below options your top **5 daily work-tasks**. All questions hereafter a building forward on these.

(Note. please select the 5 tasks that are coming close to the 5 that are coming back on a daily base during your workweek)

- ☐ Calculate dimensions,square footage, profile and component specifications, and material quantities using calculator or computer.
- ☐ Read and review project blueprints and structural specifications to determine dimensions of structure or system and material requirements.
- ☐ Draft detailed dimensional drawings and design layouts for projects and to ensure conformance to specifications.
- ☐ Confer with supervisor to determine project details such as plan preparation, acceptance testing, and evaluation of field conditions.
- ☐ Analyse proposed site factors and design maps, graphs, tracings, and diagrams to illustrate findings.
- ☐ Prepare reports and document project activities and data
- ☐ Report maintenance problems occurring at project site to supervisor and negotiate changes to resolve system conflicts.
- ☐ Inspect project site and evaluate contractor work to detect design malfunctions and ensure conformance to design specifications and applicable codes.
- ☐ Conduct materials test and analysis using tools and equipment and applying engineering knowledge
- ☐ Develop plans and estimate costs for installation of systems, utilization of facilities, or construction of structures.
- ☐ Develop project budgets by estimating the cost of project activities.
- ☐ Evaluate facility to determine suitability for occupancy and square footage availability.
- ☐ Plan and conduct field surveys to locate new sites and analyze details of project sites.
- ☐ Respond to public suggestions and complaints.
- ☐ Negotiate prices for new contracts or for modifications to existing contracts with contractors.
- ☐ Other task in Management/Leadership...
- ☐ Other task in Design...

- ☐ Other task in Analysing...
- ☐ Other task in Computing...
- ☐ Other task in Communicating...

E. Task 1: The use of Digital Technology, Skills, and Knowledge

What **digital technology** (computer enabled technology and processes) do you use to perform the work-task successfully?
'${lm://Field/1}'

- ☐ Mobile Devices and Apps
- ☐ BIM (Building Information Machine Modelling/in the cloud)
- ☐ Simulation
- ☐ Laser Scanning
- ☐ Drones
- ☐ GPS Tracking
- ☐ 3-D Printers
- ☐ Robotic Constructors
- ☐ Wearables (Google Glass, Virtual Reality, Augmented Reality)
- ☐ Big Data and Analytics
- ☐ Internet of Things (IoT:Internet connected devices in a network)
- ☐ Embedded Sensors
- ☐ Unmanned Vehicles/ aerial and non-aerial
- ☐ Computer Aided Design software (CAD)
- ☐ Map Orientation software
- ☐ Other digital technology... _____
- ☐ Other digital technology... _____
- ☐ Other digital technology... _____

I use **digital technology** for ..% in the work-task

'${lm://Field/1}'

%

0 10 20 30 40 50 60 70 80 90 100

I use digital technology for ..% in the work-task

The work-task '${lm://Field/1}'

	Not	Partially	Completely
I believe that digital technology **has changed the work-task** between 2013 and 2018	○	○	○
I expect that digital technologies **will change the work-task** between 2018-2023	○	○	○
I believe that digital technologies **replaced the need for human skills** in the work-task	○	○	○
I believe that digital technologies **enhanced human skills** in the work-task	○	○	○

I need the following **skills** to perform the work-task successfully
'${lm://Field/1}'

(Click all that are relevant.There is no minimum and no maximum)

- ☐ Reading Comprehension
- ☐ Active Listening
- ☐ Writing
- ☐ Speaking
- ☐ Mathematics
- ☐ Science
- ☐ Critical Thinking
- ☐ Active Learning
- ☐ Learning Strategies
- ☐ Monitoring
- ☐ Social Perceptiveness
- ☐ Coordination
- ☐ Persuasion
- ☐ Negotiation
- ☐ Instructing
- ☐ Service Orientation
- ☐ Complex Problem Solving
- ☐ Operations Analysis
- ☐ Technology Design
- ☐ Equipment Selection
- ☐ Installation
- ☐ Programming
- ☐ Quality Control Analysis
- ☐ Operations Monitoring
- ☐ Operation and Control
- ☐ Equipment Maintenance
- ☐ Troubleshooting
- ☐ Repairing

- ☐ Systems Analysis
- ☐ Systems Evaluation
- ☐ Judgment and Decision Making
- ☐ Time Management
- ☐ Management of Financial Resources
- ☐ Management of Material Resources
- ☐ Management of Personnel Resources
- ☐ Other Skill...

I need the following **knowledge** to perform the work-task succesfully '${lm://Field/1}'

(Click all that are relevant.There is no minimum and no maximum)

- ☐ Administration and Management
- ☐ Clerical
- ☐ Economics and Accounting
- ☐ Sales and Marketing
- ☐ Customer and Personal Service
- ☐ Personnel and Human Resources
- ☐ Production and Processing
- ☐ Food Production
- ☐ Computers and Electronics
- ☐ Engineering and Technology
- ☐ Design
- ☐ Building and Construction
- ☐ Mechanical
- ☐ Mathematics
- ☐ Physics
- ☐ Chemistry
- ☐ Biology
- ☐ Psychology

- ☐ Sociology and Anthropology
- ☐ Geography
- ☐ Medicine and Dentistry
- ☐ Therapy and Counseling
- ☐ Education and Training
- ☐ English Language
- ☐ Foreign Language
- ☐ Fine Arts
- ☐ History and Archeology
- ☐ Philosophy and Theology
- ☐ Public Safety and Security
- ☐ Law and Government
- ☐ Telecommunications
- ☐ Communications and Media
- ☐ Transportation
- ☐ Other knowledge...

F.Selected Skills

What is the DOMINANT way how you have learnt the **skills used in your work**? Select ONE way of learning for each skill (horizontal)

(Please note, dominant does not mean that you have not used other ways to learn but it is the most significant way)

I learned this skill...

	... from a **colleague at work** (for example, imitation)	...using trial and error **on the job**	...**reading** books, manuals, magazines	... while **studying** for my qualification at school	... during work-based **training**	...using the **Internet**
Management of Personnel Resources	○	○	○	○	○	○
Time Management	○	○	○	○	○	○
Social Perceptiveness	○	○	○	○	○	○
Active Learning	○	○	○	○	○	○
Persuasion	○	○	○	○	○	○
Programming	○	○	○	○	○	○
Mathematics	○	○	○	○	○	○
Equipment Maintenance	○	○	○	○	○	○
Complex Problem Solving	○	○	○	○	○	○
Negotiation	○	○	○	○	○	○
Instructing	○	○	○	○	○	○
Critical Thinking	○	○	○	○	○	○
Writing	○	○	○	○	○	○
Equipment Selection	○	○	○	○	○	○
Learning Strategies	○	○	○	○	○	○
Technology Design	○	○	○	○	○	○
Systems Evaluation	○	○	○	○	○	○
Science	○	○	○	○	○	○
Coordination	○	○	○	○	○	○
Speaking	○	○	○	○	○	○

Operation and Control	○	○	○	○	○	○
Active Listening	○	○	○	○	○	○
Management of Financial Resources	○	○	○	○	○	○
Reading Comprehension	○	○	○	○	○	○
Installation	○	○	○	○	○	○
Quality Control Analysis	○	○	○	○	○	○
Systems Analysis	○	○	○	○	○	○
Operations Monitoring	○	○	○	○	○	○
Repairing	○	○	○	○	○	○
Operations Analysis	○	○	○	○	○	○
Service Orientation	○	○	○	○	○	○
Judgment and Decision Making	○	○	○	○	○	○
Monitoring	○	○	○	○	○	○
Management of Material Resources	○	○	○	○	○	○
Troubleshooting	○	○	○	○	○	○

G.Selected Knowledge

What is the DOMINANT way how you have learnt the **knowledge used in your work?**
Select ONE way of learning for each skill (horizontal)

(Please note, dominant does not mean that you have not used other ways to learn but it is the most significant way)

I learned this knowledge...

	... from a colleague **at work** (for example, imitation)	... using trial and error **on the job**	... **reading** books, manuals, magazines	... using the **Internet**	... while **studying** for my qualification at school	... during work-based **training**
English Language	○	○	○	○	○	○
Communications and Media	○	○	○	○	○	○
Medicine and Dentistry	○	○	○	○	○	○
Design	○	○	○	○	○	○
Foreign Language	○	○	○	○	○	○
Customer and Personal Service	○	○	○	○	○	○
Sales and Marketing	○	○	○	○	○	○
Economics and Accounting	○	○	○	○	○	○
Administration and Management	○	○	○	○	○	○
Engineering and Technology	○	○	○	○	○	○
Clerical	○	○	○	○	○	○
Sociology and Anthropology	○	○	○	○	○	○
Philosophy and Theology	○	○	○	○	○	○
Telecommunications	○	○	○	○	○	○
Production and Processing	○	○	○	○	○	○

	... from a colleague **at work** (for example, imitation)	... using trial and error **on the job**	... **reading** books, manuals, magazines	... using the **Internet**	... while **studying** for my qualification at school	... during work-based **training**
Mathematics	○	○	○	○	○	○
Public Safety and Security	○	○	○	○	○	○
Food Production	○	○	○	○	○	○
Education and Training	○	○	○	○	○	○
Mechanical	○	○	○	○	○	○
Psychology	○	○	○	○	○	○
Chemistry	○	○	○	○	○	○
Law and Government	○	○	○	○	○	○
Building and Construction	○	○	○	○	○	○
Fine Arts	○	○	○	○	○	○
History and Archeology	○	○	○	○	○	○
Geography	○	○	○	○	○	○
Transportation	○	○	○	○	○	○
Therapy and Counselling	○	○	○	○	○	○
Physics	○	○	○	○	○	○
Biology	○	○	○	○	○	○
Computers and Electronics	○	○	○	○	○	○
Personnel and Human Resources	○	○	○	○	○	○

Block 8

The following **digital technologies** on the left are the ones you selected before.

(Please answer for each horizontal technology if you master working with them, if it has had any effect on your work and where you learnt working with this technology)

	I master working with this technology		This technology has ... my work			I learnt working with t technology...		
	Yes	No	...disrupted	...no effect on	...advanced	in School	while Working	during Training
Mobile devices and apps	○	○	○	○	○	○	○	○
BIM	○	○	○	○	○	○	○	○
Simulation	○	○	○	○	○	○	○	○
Laser Scanning	○	○	○	○	○	○	○	○
Drones	○	○	○	○	○	○	○	○
GPS Tracking	○	○	○	○	○	○	○	○
3-D printers	○	○	○	○	○	○	○	○
Robotic Constructors	○	○	○	○	○	○	○	○
Wearables (Google Glass, Virtual Reality, Augmented Reality)	○	○	○	○	○	○	○	○
Big Data and Analytics	○	○	○	○	○	○	○	○
Internet of Things	○	○	○	○	○	○	○	○
Embedded Sensors	○	○	○	○	○	○	○	○
Unmanned Vehicles/ aerial and non=aerial	○	○	○	○	○	○	○	○
Map Orientation Software	○	○	○	○	○	○	○	○

	I master working with this technology		This technology has ... my work			I learnt working with t technology...		
	Yes	No	...disrupted	...no effect on	...advanced	in School	while Working	during Training
Computer Aided Design software (CAD)	○	○	○	○	○	○	○	○

Please, select the 5 to 10 most important **skills** that you need **to work with the digital technologies** in your work

- ☐ Reading Comprehension
- ☐ Active Listening
- ☐ Writing
- ☐ Speaking
- ☐ Mathematics
- ☐ Science
- ☐ Critical Thinking
- ☐ Active Learning
- ☐ Learning Strategies
- ☐ Monitoring
- ☐ Social Perceptiveness
- ☐ Coordination
- ☐ Persuasion
- ☐ Negotiation
- ☐ Instructing
- ☐ Service Orientation
- ☐ Complex Problem Solving
- ☐ Operations Analysis

- [ ] Technology Design
- [ ] Equipment Selection
- [ ] Installation
- [ ] Programming
- [ ] Quality Control Analysis
- [ ] Operations Monitoring
- [ ] Operation and Control
- [ ] Equipment Maintenance
- [ ] Troubleshooting
- [ ] Repairing
- [ ] Systems Analysis
- [ ] Systems Evaluation
- [ ] Judgment and Decision Making
- [ ] Time Management
- [ ] Management of Financial Resources
- [ ] Management of Material Resources
- [ ] Management of Personnel Resources
- [ ] Other Skill...

Please, select the 5 to 10 most important **knowledge** fields that you need **to work with the digital technologies** you use in your work

- [ ] Administration and Management
- [ ] Clerical
- [ ] Economics and Accounting
- [ ] Sales and Marketing
- [ ] Customer and Personal Service
- [ ] Personnel and Human Resources
- [ ] Production and Processing
- [ ] Food Production

- [ ] Computers and Electronics
- [ ] Engineering and Technology
- [ ] Design
- [ ] Building and Construction
- [ ] Mechanical
- [ ] Mathematics
- [ ] Physics
- [ ] Chemistry
- [ ] Biology
- [ ] Psychology
- [ ] Sociology and Anthropology
- [ ] Geography
- [ ] Medicine and Dentistry
- [ ] Therapy and Counseling
- [ ] Education and Training
- [ ] English Language
- [ ] Foreign Language
- [ ] Fine Arts
- [ ] History and Archeology
- [ ] Philosophy and Theology
- [ ] Public Safety and Security
- [ ] Law and Government
- [ ] Telecommunications
- [ ] Communications and Media
- [ ] Transportation

Block 9

What is your **gender**?

Female	Male	Other..
○	○	○

What is your **age** bracket?

- [ ] 18-24
- [ ] 25-34
- [ ] 35-44
- [ ] 45-54
- [ ] 55-65

If you want to **participate in phase 2** of the research; an in-person or digital interview (max 30 minutes) Please, fill in your email below.

○ I want to participate in phase 2 of this research. My e-mail is...

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APPENDIX E-CONSENT LETTER AND FORM COMPANY

July 1st, 2018

[name]

[designation, company]

e-mail:

RE: INFORMATION LETTER TO COMPANY WITH INVITATION TO PARTICIPATE IN RESEARCH

My name is Marloes de Munnik. I am a PhD student at the Centre for Researching Education and Labour [REAL] at the school of education at the University of the Witwatersrand in South Africa. As a requirement for my PhD program, I am conducting research into the impact of digital technological change on the nature of work of construction technicians regarding work tasks and skill requirements – and the implications for education and training. My research is entitled; 'Linkages between digital technological change, human skills and workforce development: the case of the construction technician'.

The aim of this research is to analyse 'the impact of digital technology on workforce development with a focus on the nature of work and the changing demand for the 'skills' of construction technicians, and on the relationship of this with their educational preparation for work'. Therefore, I selected two countries with different innovative contexts for my research, namely; the United Arab Emirates and South Africa.

The study is focusing on the case of the construction technician. [company] was selected to participate in the study to gain insights on digital technological change and skill requirements for construction technician professionals in the construction industry. This will be achieved through surveys completion and interviews among civil engineering construction technicians (different terminology of the job titles exist and I will advise accordingly on the exact framing) and their managers. In the case that [company] consents to participate, I would require your assistance in purposively selecting all relevant employees to participate in a survey that will take 20-40 minutes to complete, on tasks, skills and technology in their work. In addition, I require in a later phase, an interview with up to 5 construction technicians, and up to 5 managers to follow up on the results of my workers survey. In this semi-structured interview, I will ask them in-depth questions about the

concepts of technology, tasks, skills and education in the construction industry. The interview lasts for a maximum of 30 minutes per employee.
The timeframe for conducting the Survey of my research is envisaged to take place between July and September 2018, and the interviews envisaged to take place between October and December 2018. For the survey, I would therefore ask to complete the provided survey within this timeframe.

I will ensure anonymity and privacy of individual participants (employees and their managers) and I work with pseudonyms instead of names in any reports and publications. Furthermore, privacy regarding company details is completely ensured and no specific outcomes connected to company names will be made publicly without the written consent of [company]. If required, a non-disclosure agreement can be made and signed by both parties. The data collected will be analysed by myself and documented in my research report. This specific data is meant for academic purposes, including books, journals and conference proceedings. All research data will be kept safely in a secured and password protected computing device and raw data will be destroyed after five years upon completion of the study.

Your company is important for the research. However, participation is completely voluntary and you may decline to participate at any stage of the research. Therefore, I would like to invite [company] to participate in the research and request permission from the president of [company].

Should you require further information during the research or before, please do not hesitate to contact me on 00971 (0) 55 955 2879 or marloesdemunnik@gmail.com. A summary of the report and findings can be made available to you electronically upon envisaged completion in March 2020. Please, kindly advise if you would wish to receive these.

Thank you in advance for your kind consideration.

Yours sincerely, Marloes de Munnik
PhD Candidate at University of the Witwatersrand – South Africa
Research Protocol Number: 2018ECE009D

EXPLORING LEARNING FOR WORK IN THE CONTEXT OF DIGITAL WORK TECHNOLOGIES

COMPANY CONSENT FORM

Regarding the research with title: LINKAGES BETWEEN DIGITAL TECHNOLOGICAL CHANGE, HUMAN SKILLS AND WORKFORCE DEVELOPMENT: the case of the construction technician

Research Protocol Number: 2018ECE009D

I would appreciate if **[company]** could please acknowledge receipt of the information letter of my research requesting permission to conduct my research.

[company] herewith acknowledges that:

	YES / NO
1.The information letter has been read, understood, and its content acknowledged	☐ ☐
2.Involvement is voluntary and selected participants may choose not to participate or to withdraw their consent at any given time without any negative consequences.	☐ ☐
3. Interviews with selected participants will be audio-recorded to ensure the accuracy of the transcription. Consent will be obtained separately for recording. All data and transcripts will be kept securely and destroyed after 5 years of completion of this project.	☐ ☐
4. The selected participants their inputs will be anonymous and pseudonyms such as participant 1 will be used to ensure anonymity. Furthermore, the anonymity of the company is also ensured.	☐ ☐
5. The selected participant's individual consent will be obtained before data collection begins. (E.g., Survey and Interview)	☐ ☐
6. The data collection process will not interfere with the day to day running of the organisation.	☐ ☐
7. The research findings will be used for academic purposes, including books, journals and or conference proceedings and to inform policy debates.	☐ ☐

I, [name] (Head of company..) acknowledge the information stated above, and grant permission for ***Marloes de Munnik*** to conduct research within; **[company]** in 2018.

Signature: _____ Date: _____

**I wish to receive an electronic summary of the research findings upon completion of the study on the following email address:*

_____@_____

APPENDIX F-PARTICIPANT INVITATION SURVEY

Dear … Employee September, 2018

RE: FORMAL INVITATION LETTER TO PARTICIPATE IN RESEARCH WITH PROTOCOL NO 2018ECE009D

My name is Marloes de Munnik. I am a PhD student at the Centre for Researching Education and Labour [REAL] at the school of education at the University of the Witwatersrand in South Africa. As a requirement for my PhD program, I am conducting research into the impact of digital technological change on the nature of work of engineering (associate) professionals working in the construction industry regarding work tasks and skill requirements – and the implications for learning for work. My research is titled; 'Linkages between digital technological change, human skills and learning for work'.

The aim of this research is to analyse 'the impact of digital technology on workforce development with a focus on the nature of work and the changing demand for the 'skills' of engineering (associate) professionals, and on the relationship of this with their educational preparation for work'. Therefore, I selected two countries with different innovative contexts for my research, namely; the United Arab Emirates and South Africa.

I would like to invite you to participate in the second phase of this research study. If you agree, participation will include a semi-structured in-person/digital interview between October - December 2018 of 30 minutes max.

Your participation is highly important for the research. However, participation would be completely voluntary, and you may decline to participate at any stage of the research. I will ensure anonymity and privacy of participants and work with pseudonyms instead of names in any publications, including the thesis document. No specific outcomes connected to your names will be made publicly or shared with anybody from your company.

Should you require further information during the research or before, please do not hesitate to contact me on 00971 (0) 55 955 2879 or marloesdemunnik@gmail.com. A summary of the report and findings can be made available to you electronically upon envisaged completion before March 2020. Please, kindly advise if you would wish to receive these.

Thank you in advance for your kind consideration.

Yours sincerely, Marloes de Munnik - PhD Candidate at University of the Witwatersrand – South Africa

PARTICIPANT CONSENT FORM

Regarding the research with title: LINKAGES BETWEEN DIGITAL TECHNOLOGICAL CHANGE, HUMAN SKILLS AND LEARNING FOR WORK: the case of the engineering (associate) professional

Research Protocol Number: 2018ECE009D

	YES / NO
1.I have read and understand the information sheet	☐ ☐
2.My involvement is voluntary, and I understand that I may choose not to participate or to withdraw my consent at any given time without any negative consequences.	☐ ☐
3. I will not be advantaged, disadvantaged or receive any form of remuneration for participating	☐ ☐
4. My personal inputs will be anonymous and pseudonyms such as participant 1 will be used to ensure my anonymity. Furthermore, the anonymity of the company is also ensured.	☐ ☐
5. I do not have to answer questions if I am not feeling comfortable to do.	☐ ☐
6. My personal details will be kept private and research findings will be used with a pseudonym like a number or letter in writing up of results.	☐ ☐
7. The research findings will be used for academic purposes, including books, journals and or conference proceedings and to inform policy debates and my name will not reflect in any of these	☐ ☐

I, _____ [name],

acknowledge the information stated above, and agree to participate in the research stated above.

By signing below, I [name] give consent to participate in the research:

Signature: _____ Date: _____

APPENDIX G-ETHICAL CLEARANCE APPROVAL

Wits School of Education

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

27 St Andrews Road, Parktown, Johannesburg, 2193 • Private Bag 3, Wits 2050, South Africa
Tel: +27 11 717-3221 • Fax: +27 11 717-3009 • E-mail: enquiries@educ.wits.ac.za • Website: www.wits.ac.za

29 June 2018

Student Number: 1745906

Protocol Number: 2018ECE009D

Dear Marloes Munnik

Application for Ethics Clearance: Doctor of Philosophy

Thank you very much for your ethics application. The Ethics Committee in Education of the Faculty of Humanities, acting on behalf of the Senate, has considered your application for ethics clearance for your proposal entitled:

'Linkages between digital technological change, human skills and workforce development: the case of the construction technician'

The committee recently met and I am pleased to inform you that clearance was granted. Please use the above protocol number in all correspondence to the relevant research parties (schools, parents, learners etc.) and include it in your research report or project on the title page.

The Protocol Number above should be submitted to the Graduate Studies in Education Committee upon submission of your final research report.

All the best with your research project.

Yours sincerely,

MMaseko

Wits School of Education
011 717-3416

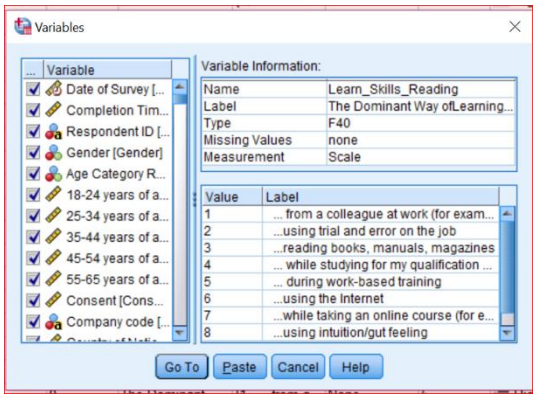
cc Supervisors - Professor Stephanie Allais & Dr Reuben Dlamini

APPENDIX H-DATA GENERATION PROCEDURE IBM-SPSS-25

PROCEDURES AND SPSS SYNTAX

Procedure first analysis learning Skills for work

- Variables
  - Variables that were asking about learning the skills used in daily work-task top 5 learn_Skills (35x)
  - Variable information in SPSS:
    - 9 Values / Labels from Workers' survey



- Data cleaning raw variables already happened
- Generating frequency tables in SPSS
- Combining frequency tables in Excel in one table for learning skills for work (used copy paste + check afterwards to prevent mistakes)
- Calculating sums for (1) total selections of learning mode and (2) total selections of skill
- Calculating % tables from the generated frequency tables (1) total selections learning mode / total selections all learning modes (2) total selections skill/ total sample (41) Survey question

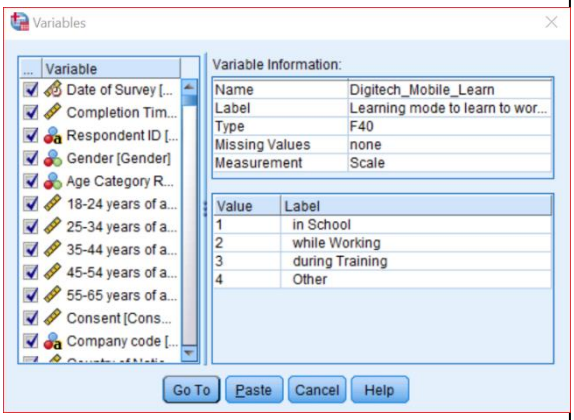
SPSS Syntax code

```
FREQUENCIES VARIABLES=Learn_Skills_Reading
Learn_Skills_Listening
Learn_Skills_Writing
Learn_Skills_Speaking
Learn_Skills_Maths
Learn_Skills_Science
Learn_Skills_Thinking
Learn_Skills_Learning
Learn_Skills_Strategies
Learn_Skills_Monitoring
Learn_Skills_Perceptiveness
Learn_Skills_Coordination
Learn_Skills_Persuasion
Learn_Skills_Negotiation
Learn_Skills_Instructing
Learn_Skills_Service
Learn_Skills_ProblemSolving
Learn_Skills_OpAnaly
Learn_Skills_TechDesign
Learn_Skills_Selection
Learn_Skills_Installation
Learn_Skills_Programming
Learn_Skills_QCAnaly
Learn_Skills_OpMonitor
Learn_Skills_OpControl
Learn_Skills_Maintenance
Learn_Skills_Troubleshooting
Learn_Skills_Repairing
Learn_Skills_SystAnaly
Learn_Skills_SystEvalu
Learn_Skills_Decision
Learn_Skills_TimeMan
Learn_Skills_ManFinRes
Learn_Skills_ManMatRes
Learn_Skills_ManPersRes
  /ORDER=VARIABLE.
```

***** the same principles were applied to the knowledge sections

Procedure first analysis learning to work with digitech

- Raw data cleaning of variables
    - Variables that were asking about learning the Digitech used in daily work-task top 5 (13x) Digitech_Mobile_Learn
    - Variable information in SPSS:
        - 4 Values / Labels from Workers' survey



- Generating frequency tables in SPSS
- Combining frequency tables in Excel in one table for learning digitech for work (used copy paste + check afterwards to prevent mistakes)
- Calculating sums for (1) total selections of learning mode and (2) total selections of Digitech
- Calculating % tables from the generated frequency tables (1) total selections learning mode / total selections all learning modes (2) total selections Digitech/ total sample (41) Survey question(s)

SPSS Syntax code

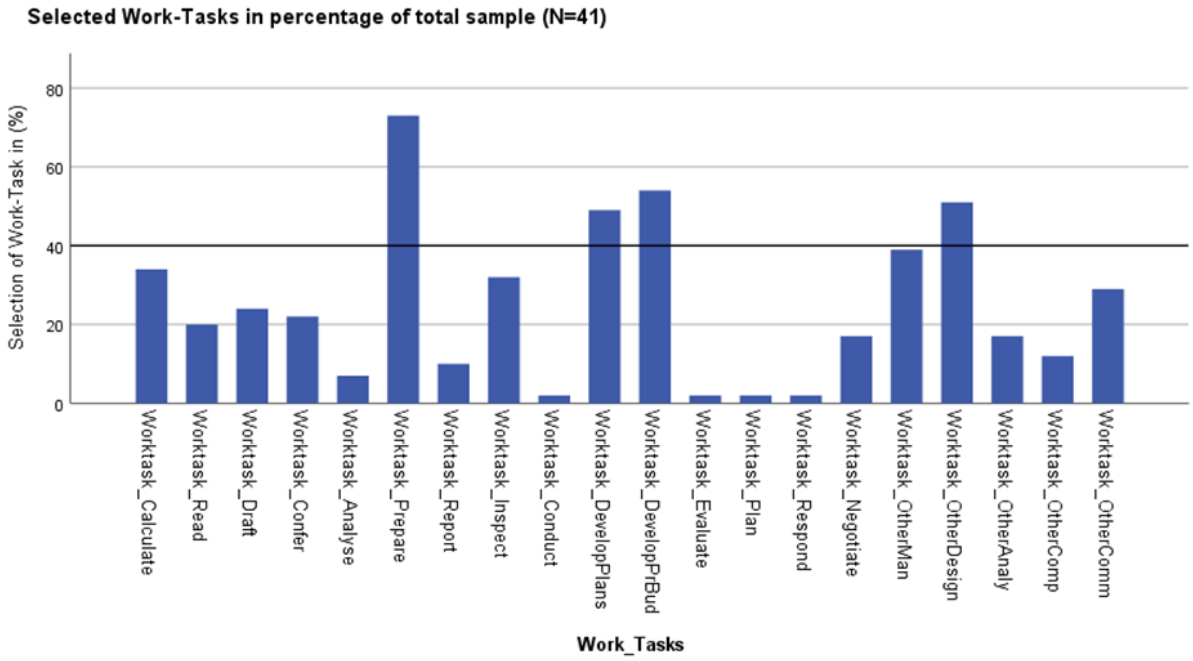
```
FREQUENCIES VARIABLES=Digitech_Mobile_Learn
Digitech_BIM_Learn Digitech_Simulation_Learn
Digitech_Scanning_Learn Digitech_Drones_Learn
Digitech_GPS_Learn Digitech_3D_Learn
Digitech_Robotics_Learn Digitech_VRAR_Learn
Digitech_BigData_Learn Digitech_IOT_Learn
Digitech_Sensors_Learn
Digitech_UnmannedVeh_Learn
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 /FORMAT=DFREQ
 /ORDER=VARIABLE.
```

APPENDIX I-DEFINING AND SELECTING THE CORE WORK PRACTICE

Two levels for the unit of analysis, each with two sublevels, were used since the importance of a practice unit of analytical analysis was identified following sociomaterial theoretical sensibilities. Namely, the engineering practice as the unit of analysis and the engineering professional working in the practice with the professional group and country were considered when discussing the results. By keeping the analytical focus on professional work tasks conceptualised as work-practice, the survey results were first used to define the core work practices. For the reason that all professionals were qualified as engineering professionals and both managing and technical were involved in engineering work, the analysis of core practices was done by treating them as one group of 41 engineering professionals, but their possible variation was taken into account and is briefly discussed.

The first step in defining the core daily work practice of the engineering professionals was to make their work practices visible. Therefore, the first analytical task was to address the composition of work practice based on the selected work tasks in the survey data. The questions in the survey asked the respondents to select explicitly their recurring top-five daily work tasks. This was generated in IBM SPSS-25 on the survey data and showed that the top five daily work tasks conceptualised as work practices among the complete sample of 41 survey respondents were: *preparing project reports*, developing project budgets, *developing construction plans*, other design, and other management. See column 2 in the figure below for the complete descriptions of the work practices for the complete group of 41 engineering professionals.

Figure 40.Daily engineering core work tasks in the survey



However, it is also important to consider variation based on the different types of engineering professionals in the survey, and this analysis is provided in the table below.

Table 32.

Daily engineering core work tasks in survey by professional group

Table of core engineering work practice specified by professional group (% of N=41)

Nr	Work practice	%Technical	%Engineering	%Managing	%Total
1	Calculate dimensions,square footage, profile and component specifications, and material quantities using calculator or computer.	57	36	17	34
2	Read and review project blueprints and structural specifications to determine dimensions of structure or system and material requirements.	43	18	8	20
3	Draft detailed dimensional drawings and design layouts for projects and to ensure conformance to specifications.	0	45	0	24
4	Confer with supervisor to determine project details such as plan preparation, acceptance testing, and evaluation of field conditions.	57	14	17	22
5	Analyse proposed site factors and design maps, graphs, tracings, and diagrams to illustrate findings.	0	14	0	7
6	Prepare reports and document project activities and data	71	77	67	73
7	Report maintenance problems occurring at project site to supervisor and negotiate changes to resolve system conflicts.	14	5	17	10
8	Inspect project site and evaluate contractor work to detect design malfunctions and ensure conformance to design specifications and applicable codes.	29	36	25	32
9	Conduct materials test and analysis using tools and equipment and applying engineering knowledge	14	0	0	2
10	Develop plans and estimate costs for installation of systems, utilization of facilities, or construction of structures.	71	50	33	49
11	Develop project budgets by estimating the cost of project activities.	43	45	75	54
12	Evaluate facility to determine suitability for occupancy and square footage availability.	0	5	0	2
13	Plan and conduct field surveys to locate new sites and analyze details of project sites.	0	0	8	2
14	Respond to public suggestions and complaints.	0	0	8	2
15	Negotiate prices for new contracts or for modifications to existing contracts with contractors.	14	5	42	17
16	Other task in Management/Leadership...	29	27	67	39
17	Other task in Design...	14	68	42	51
18	Other task in Analysing...	0	18	25	17
19	Other task in Computing...	14	14	8	12
20	Other task in Communicating...	29	23	42	29

Note:

(a) Counts generated with IBM SPSS-25 on non-missing value in the work practices, based on the STWL survey

(b) Table created in MS Excel by calculating the percentage (%) of total N (N=41)

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The table above reveals that variations among the technical, engineering and management respondents can be identified although the selection of three of the previously mentioned core engineering work practices was consistent among the professional groups as can be seen by focusing on the similarity of the blue colouring in the same row. However, this was not the case for the work practices *other design* and *other management.* The former was more selected among the management and engineering group, which combined made up the biggest share of the respondents and the latter was more selected among only the management group, which made up about 30% of the respondents. Due to the extreme diversity of *other* in both work practices which the respondent could specify in text, the latter two were not considered relevant for further analysis in this thesis. Therefore, a selection consisting of *prepare project reports* (N=30), develop project budgets, and *developing construction plans* (N=20) were considered to take further. Given the fact that the participants who signed up for the interview after the survey stage selected at least one of the practices of *prepare project reports* and *developing construction plans*, the decision to focus on these two practices during the interviews was made. The variations among the professionals that did not select the work practice *prepare project reports* are shown in the table below.

Table 33.

Variations among non-selections for preparing project reports

		Work practice selections from the missing values in work practice Prepare reports… (N=11 missing values)															
Context *b*	Gender	Read	Calculate	Draft	Confer	Inspect	Plan	Report	Develop plans	Develop Project budgets	Negotiate	Respond	Other Analyse	Other Management	Other Comp	Other Design	Other Comm
Well developed	Male												1	1	1	1	
Well developed	Male		1	1	1				1							1	
Well developed	Male	1		1					1							1	
Well developed	Male	1			1	1										1	
Well developed	Female								1				1		1	1	
Medium developed, medium educated	Female	1				1	1		1							1	
Medium developed, low educated	Male												1	1	1	1	
Medium developed	Male									1	1		1	1			
Medium developed	Male									1	1	1	1	1			
Medium developed	Male	1	1		1				1	1							
Medium developed, low educated	Male		1					1			1			1		1	
	Totals (count)	*4*	*3*	*2*	*3*	*2*	*1*	*1*	*5*	*3*	*3*	*1*	*5*	*5*	*3*	*8*	

Note:

(a) Counts calculated with IBM SPSS-25 on non-missing values in the work practice prepare reports

(b) The context is based on the development of the location, where the professional is performing his/her practice and when this differs with educational context, it is specified in the first column

Source data: 2018-2019 STWL-survey (de Munnik, 2020)

The variety of roles, work contexts, age groups, years of experience and the selection of a variety of other practices showed that the professionals which did not select the work practice *prepare project reports*, selected in fact a variety of other work practices. If ignoring the *other* work practices for the same reason as indicated before, as they are too complex and variable, the alternative work practices can be less likely associated with one specific engineering level nor do they have a specific attribute. However, age could be an associated attribute because half of the missing values (6) included professionals with more than 10 years' work experience. Although, at the same time, these professionals were managing professionals. The context of development in their work and their location seemed however less relevant. The same is the case with analysing the work practice *developing construction plans*. Although 21 professionals did not select this work practice, the spread of the respondents that did not select this work practice varied across different contexts, work roles, age groups, and experience which makes it likely that a specific engineering level must not be excluded when addressing this work practice.

Therefore, based on the degree of variation in both context and professional attributes among the missing values in the work practices *developing construction plans* and *prepare project reports*, these two core engineering work practices were selected in the research to focus on when analysing the survey results, and both for the interview focus in the qualitative part of the research and for subsequent practice analysis. The practice-theory lens that was adopted shortly before the second empirical phase resulted in a new data analysis phase also for the quantitative part of the study, since the final focus on two core engineering work practices was identified. I cleaned the data again and transformed it into a usable format by using IBM-SPSS syntax code. The sample used for the new data generation based on the practice approach resulted in the selection of two different but similar core engineering practices, namely, that of *preparing project reports* and that of *developing construction plans* respectively, each with N=30 and N=20 survey respondents, and N=5 and N=2 interview informants.

APPENDIX J-CONSENT INTERVIEW INFORMANTS

PARTICIPANT AUDIO CONSENT FORM

Regarding the research with title: LEARNING FOR WORK IN THE CONTEXT OF DIGITAL TECHNOLOGY: the case of the construction industry engineering associate professional conducted by Marloes de Munnik

Kindly select YES OR NO to indicate that you are informed about giving consent for audio recording and transcribing of your interview

	YES / NO
1. My involvement is voluntary, and I understand that I may choose not to participate or to withdraw my consent at any given time without any negative consequences.	☐ ☐
2. I will not be advantaged, disadvantaged or receive any form of remuneration for participating.	☐ ☐
3. My personal details will be kept private and research findings used with a pseudonym like a number or letter in writing up the results.	☐ ☐
4. The research findings will be used for academic purposes, including books, journals and or conference proceedings and to inform policy debates and my name will not reflect in any of these.	☐ ☐
5. Audio-recordings of my interview will be used to make sure that the researcher can use the data precisely at a later stage to improve research results.	☐ ☐
6. All audio-taped material and the transcribed responses (the textual form of the audio-recording) will be stored safely in the researcher's private office and destroyed after 5 years of completion of this project.	☐ ☐

I, _____ [name],

acknowledge the information stated above, and agree to be audio-taped and transcribed during the interview.

By signing below, I give consent for interviews to be audio-taped and transcribed.

Signature: _____ Date: _____

APPENDIX K-INTERVIEW PROTOCOL TEMPLATE

<table>
<tr><td colspan="3">INTERVIEW TEMPLATE</td></tr>
<tr><td colspan="3">work-task 1 ‘(work-task long description)’</td></tr>
<tr><td colspan="3">Name: (Survey ID) Date Digital/ In-Person</td></tr>
<tr><td>Time</td><td>Introduction, start interview and role confirmation</td><td>Aim and theme</td></tr>
<tr><td>5</td><td>‘small talk’
1. ‘How was your day so far?’

‘Let me ensure you that all what you say is confidential and will be used for the purpose of my research without connecting results to your name. Your personal details will always be kept confidential and the recording will be used only to analyse the interview for my research data’

2. ‘Do you understand your privacy, and do you give your consent to participate and audio record your interview?’
3. ‘During the interview, I will keep an eye on the time, and I might interrupt you to proceed to the next guiding question, this is not meant to be mean but to be able to get the most out of your valuable time ‘

Demographic questions part 1
4. ‘Can I reconfirm that you are a (jobtitle) working in the ‘country’?’</td><td>This question is envisaged to create an ‘environment’ of trust and ensure the privacy of the respondent.

<table><tr><td>Demographics</td><td></td></tr><tr><td>Gender
Nationality
Age bracket
Residency and time
Highest level academic schooling
Years since schooling
Experience construction industry
Experience current job
Highest level academic engineering
Work-based training last 5 yrs</td><td>Female/Male
National
Years
.. resident, yrs
level
.. yrs
.. yrs
.. yrs
.. level

.. days</td></tr></table>
This is meant to reconfirm the consent of the informant.

<table><tr><td>Role + location</td><td></td></tr><tr><td>Job title
Company
Residency</td><td>Snr civil engineer
Aurecon
UAE</td></tr></table>
This question asks to reconfirm the role and location of the informant. Some non-sensitive demographics can be checked on the way but that is not the main goal nor focus.</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>5-20</td><td>Work context setting and learning for work questions</td><td>Aim and theme for analysis</td></tr>
<tr><td></td><td>
5. ‘You selected the work-task ‘(work-task x)’ .We will focus on this work-task and if there is time left or if you are ok to continue with the interview, I would like to further discuss your learning for work in general.

6. ‘Can you elaborate on this work-task (work-task x)? Why have you selected this work-task and tell me more about what you do in practice? What are the sub-tasks (activity units) to perform this work?

7. Where does this work takes place? Context, can you describe the environment? on site? Off-site? Clients? Office? Etc.

8. What other people are involved? What is their role and your role?

9. Are any artefacts (tools) involved in this practice? Specific digital technology?
</td><td>
This question asks for a confirmation of a main work-task. Based on the response in phase one. This result in the question being more closed in nature but allows to focus on the task-based approach and not lose valuable time with having informants ‘hang in the unknown’

<table>
<tr><td>Work-task</td><td>Description</td></tr>
<tr><td>Prepare</td><td>Prepare reports and document project activities and data</td></tr>
</table>

<table>
<tr><td>Why</td><td></td></tr>
<tr><td>Practice</td><td></td></tr>
</table>

<table>
<tr><td>Sub-task</td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

As I do acknowledge that a broader perspective on learning for work is essential as workers ‘skills’ are not the only factors involved, I want to include components of the practice theory to develop a broader understanding of their work in practice. (space, time, people, context, artefacts)

<table>
<tr><td>Context</td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

<table>
<tr><td>Relationships</td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

<table>
<tr><td>Artefacts</td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

<table>
<tr><td>Digitech</td><td>Big Data & Analytics</td></tr>
<tr><td>Share in work-task</td><td>..%</td></tr>
</table>

Can I conclude that this work-task has a low/fair/good and large/low variance share of digital technology usage?

</td></tr>
</table>

10. Where have you learnt to do the activities of this work-task? Can you tell me more what is according to you the place where you have learnt to do this work-practice? You can specify by activity if you want.

11. How have you learnt this practice? (colleagues, repeating etc)

12. You have selected the following skills important to perform this work-task, can you explain why you have selected them and at the same time tell me why you have selected where you have learnt them?

**focus on the 5 skills that were part of the top 5 among all results for this work-task*

These questions are meant to create an in-depth understanding of informants' learning for work. The exact framing of the questions depends on the answer to the previous questions

Learning for work	

Learnt from who?	

Skills (no tot)	*Learning mode*
Top 5 selections among all informants	
… (bold if one of top 5)	*… (learning mode)*
…	*… (learning mode)*
…	*… (learning mode)*
…	*… (learning mode)*
…	*… (learning mode)*

Most selected learning mode	*Why?*
… (learning mode) (nox)	

Knowledge	*Learning mode*
Top 5 selection among all informants	
…	*… (learning mode)*
…	*… (learning mode)*
…	*… (learning mode)*

13. You have selected the following knowledge important to perform this work-task, can you explain why you have selected them and at the same time tell me why you selected where you have learnt them?

**focus on the 5 knowledge that were part of the top 5 among all results for this work-task*

…	… *(learning mode)*
…	… *(learning mode)*

Most selected learning mode	***Why?***
… *(learning mode) (..x)*	

20-25 **Elaborate on impact of digital technology on work**

14. Can you elaborate on what aspect of this work-task changed between 2013 and 2018 and what part do you expect to further change till 2023?

15. You answered that the DigiTech's '(digitech's). enhanced human skills 'not/partially/completely ? Can you elaborate?

Digitech	***(Selected Digitechs)***
Share in work-task	*..%*
Digitech changed 2013-2018	*(Not/Partially/Completely)*
Digitech will change 2018-2023	*(Not/Partially/Completely)*
Digitech replaced human skills	*(Not/Partially/Completely)*
Digitech enhanced human skills	*(Not/Partially/Completely)*

16. Can you elaborate on your learning of '(digitech's) while ..(learning mode)?

Digitech	***Digitech X1***
(Digitech X1) Mastery *Technology has … my work* *I learnt working with this technology…*	 *(No/Yes)* *(Disrupted/No effect on/Advanced* *(In school/ While working/ during training/ other)*

17. Can you tell me why you selected the skills and knowledge as important to work with the digital technologies in your work?

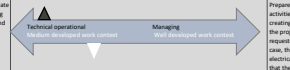
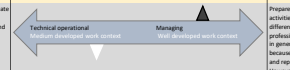
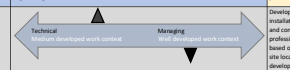
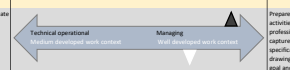
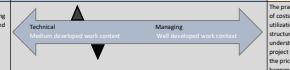
Skills (.no)	***Learning mode***
…	…

Learning mode (x)	..

Knowledge (…no)	***Learning mode***

		… … *Learning mode (x)* ..
25-30	Closing of interview	Theme for Analysis
	‘We are now at the end of the interview and I understand that your main learning for work is as follows …, and your main… correct? I would like to thank you for your time and valuable contribution to my research. I can share my findings once I completed my PhD program with you. Are you interested to receive these? (if yes, please send me your preferred e-mail). Do you have any questions for me or concerns that you want to share with me?’	This final ‘text’ is meant to close the interview by restating the main direction of the answers, thank the respondent and give them some form of reward by offering to send them the results.

APPENDIX L-DATA GENERATION INTERVIEW 5 PRINCIPLES

	Engineering level								5 principles of engineering practice					Learning for practice				
empirical case, context and attributes	1	2	3	4	5	6	practice		1. knowing in practice	2.socio-material	3. embodied/relational (doings)	4.exist and evolve in historical and	5.emergent	Learning for practice	Future learning needs for practice and DigiTech	Learning individual knowledge for practice	Learning individual skills for practice	Conclusion
empirical cases (2) of a shared practice among the engineering professionals in the study of Reich, A., Rooney, D., Gardner, A., Willey, K., Boud, D., & Fitzgerald, T. (2015). Engineers' professional learning: A practice-theory perspective. European Journal of Engineering Education, 40(4), 366–379.																		
example 1 Reich et al.2015:Sitewalks							One of the engineering practices identified was site walk practice (see Rooney, (2014) for further details). We use this to illustrate a practice theory perspective on engineering practice, around the five principles for theorising practice described above. For site engineers, the site walk is the routine way to start the day. The site engineer looks for anything that has changed overnight, e.g.	The site walk practice was illustrative of knowing-in-practice. Despite extensive design and planning, 'knowing' the practice is enacted in the site. As one engineer stated, a site walk undertaken as part of the tender preparation phase of a project: ...most engineering jobs you can't price,	The human actors included a diverse range of people from the senior supervisor, various consultants, an environmental team or scientists, construction manager and the client, to the foreman, service managers, labourers, diggers or leading hand, a blast crew, project manager,	Site walks can also be regarded as embodied and relational. They involve more than the thinking and cognitive processes in people's heads and the 'static ' knowledge of engineering design. They involved bodies —the movement of walking, driving and even sometimes flying over the site.Site	For site engineers, the site walk is the routine way to start the day. The site engineer looks for anything that has changed overnight, e.g. excavation collapse/erosion, vandalism, protective covers dislodged by wind, rainwater damage or ponding, because the results of any	Finally site walks were emergent. They emerged without determinacy or predictability to be able to specify changes in advance. As the engineers and their fellow participants were going around the site they used their professional knowledge of the site but needed to take account of changes daily, based on many extraneous				**The site walk practice seen through a practice theory lens is seen not as a 'straight-forward', static and easily defined practice. As illustrated above, it is shaped by human and non-human actors, historical and social contexts, materiality and the highly relational nature of the practice; it is also emergent and not predictable in advance. The site walk practice is also an important site of learning as the engineer's learning is enmeshed in the relational practices with many other professions and occupations. It requires the 'emerging professional', as described in the beginning of the article**
example 2 Reich et al.2015:Review meetings							Another shared practice among the engineers in the study was what was referred to as 'reviews' or review meetings. These are regular meetings between major stakeholders in a project to compare current actual progress to the planned progress – both in timing and in money spent. Having design review meetings is a way to minimise the risk of going over time and over budget. As one		This practice is mediated by materiality. The 'things' at a design review included specifications, drawings "Basically going through stacks of plans" (Tim), work schedules, budgets, laptops, iPads, PowerPoint slides, Blackberries, mobiles, pens and diaries (to name just a few). However, again, as	This practice is also relational. It occurs in relation with others involved in the practice. These 'others' represent a range of roles within the project (e.g., clients, sub-contractors, designers, site managers, etc.). The meeting practice is not static, bounded and predictable. Engineers with	Similarly the design meeting practice is not confined to the particular time and space of the allocated 'meeting'. Much work related to the meeting practice happens before and after a particular meeting. For example several staff commented on the internal meetings held prior to the	Finally, these practices are emergent. Practices exist, they evolve over time and over contexts; they change in the light of circumstances. As one engineer stated, Every job's different, every job has a different contract and every job has a different relationship between the contractor, the design and the client.				**Third, this practice approach to professional learning provides a new perspective on how continuing professional learning occurs. It requires thorough analysis of embedded practices in workplaces and the entwined learning opportunities. This shifts the focus of understandings of continuing professional learning of engineers from attributes of the learner (knowledge, skills, attitudes) to the attributes of the practice (challenges, opportunities, interactions, etc.). It thus positions learning itself not as a technical matter of knowledge acquisition,**
empirical cases (7) of a shared practice of 'developing a project plan and making a report' among the engineering professionals in my study:																		
empirical case 1									1. knowine in practice	2.socio-material	3. embodied/relational (doings)	4.exist and evolve in historical and	5.emergent					
empirical case EP1 is a male and full engineering qualified (graduate level) electrical assistant engineer working in a larger engineering construction firm, based in a medium developed work context and operating in various countries across the globe.							Prepare reports and document project activities and data which is understood as creating an understanding at the beginning of the project, based on the requirements of the requested production party (internal). In this case, the request is based on developing an electrical machine. The professional indicated that the [team] first start with a planning in where they assess what they need regarding		This practice is mediated by materiality in different ways. Firstly, because the preparation for the project, which information eventually goes into the report is based on planning and preparing the supplies required to develop the project. Because sometimes, the required supplies are not easily	This practice is relational because it develops in relation to others who contribute directly to the scope of work in the project or give approval for the project plan, or supply the materiality's required to develop the project. The dependency and relations with supplies also result in the practice	The practice is specific to the requirements of the client and the site in where the project has to be placed and also because some of the supplies are bounded to a local context and extra time to order from other countries is sometimes not directly available.	The professional in this example has seen the practice change over time and with the use of digital technologies some components of the practice were made easier and the time factor seems to play a significant role as a result.	The professional in this case indicated that he learnt most of the basic skills in this work-practice at work and by experience, such as trial-and-error on the job. In where he indicates that by such learning, he learns both sides of the scenario, the good and the bad. Learning was often initiated based	The professional has a goal to learn programming so he can improve a part of his practice, in where he needs to study a project easier by developing a search database with older projects. He indicates that for that he is learning to programme with Python but he does not master this yet. In the survey, he indicates that to work with DigiTech, skill such as installation, programming and repairing are essential to have and except programming which he indicates learning by internet, the others are learnt by trial	The professional selected as opposed to skills, fewer knowledge as required for his work. He selected five knowledge items of which 3 disciplinary and 2 social. In the interview he elaborated on his way of learning by using the internet for two of his knowledge areas. For this professional, he likes to use an internet search to search for good practice examples from something that he doesn't know, motivational video's for management issues, as well as searching	The professional in this case first selected in his survey eleven skills, six more disciplinary (technical) oriented and the rest general required for successful execution of this work-practice. He indicates that general skills such as speaking are,although not directly necessary, helpful to have while being a member of this practice. For example, when asking for somebody's help, he indicates that	**The developing a project plan and prepare the report seen through the practice theory lens is helpful as it shows that the practice includes different actors, both human and non-human who have relations with each other and impact the practice on its turn. Both human and non-human actors do exist in space and time and are thus embodied and relational. It also shows that the practice in this empirical case is situated in a localised context that mediates the availability of actors and changes the practice on its turn. The relation between the human and non-human actors is perceived in a**
Example of quotes or survey answers supporting the above discussion EP1										*Simulation means whenever we do a project and when we do the program, we do simulate, with*	*normally means we normally deal with time. How much time we think it's progress meeting then*	*But we need it to see if it is maybe not available in [country] market or outside markets'[EP1]*	*Again, I mentioned in the recent year that the digital technology is giving us a lot of help. Like before, I told you*	*But normally, we take help from our some position...as we are more open and more... more... we*	*I am not doing But I'm trying to learn some programming language like Python. Actually, I have now starting to learn the Python language so I want to... like before*	*Normally internet means, the YouTube and the Google. Google normally, we put it stuff like' how to do this administration and management skill?' It*	*The basics, we have learned from the school and upgrading in the workplace.' EP1J8 'Yeah not... like in projects, some of the*	
Key-terms/sentences that come up for me							objective, meet and plan, required materiality's, assessment of time			Materiality to simulate outcome of project design and test, test use, positive materiality mediated	Power and professional judgment issue, dependency on materiality positive relation with	Context dependent, supply agency	Changes in practice, time improvement due to digital technology	Learning both scenarios', learning together, power and professional judgement issues,	Aware of future needs, programming, learning by trial and error	Best practice, internet learning,	Knowing in practice/learning in practice	**Positive agency of DigiTech in this practice although it changes and shapes the practice in unpredictable ways. Rather the positive is perceived as opposed to the negative. Relations with human-actors**
empirical case 2									1. knowing in practice	2.socio-material	3. embodied/relational (doings)	4.exist and evolve in historical and	5.emergent					
empirical case EP2 is a male and full engineering qualified (graduate level) managing senior engineer working in a larger engineering construction firm, based in a medium developed work context and operating in various countries across the globe.							Prepare reports and document project activities and data which is understood differently according to the multiple roles the professional takes up in the organisation but in genera seen as he outcome of his work because for al of his work he needs to plan and report back to the right decision makers. However, if his role is concerned with starting a new project, the first thing is to assess the		This practice is mediated by materiality in the way that it enables the decision making process that is the input for the developing plans, monitoring and preparing reports as well as it includes the 'tools' used in this process. For example, big data and analytics seem to be a relevant	Taken into account the different actors involved in this practice, the network includes different levels of authority and decision making that on its turn shape the relations of both the human and nonhuman actors involved. The current professional has limited final authority for final decisions and	The work-practice of preparing the report is not bound to one specific location in the sense that multiple parties on the project are involved who each can operate at different locations. If just focusing on the professional as a member of this practice, the practice takes predominantly place in his own	The practice seems to have emerged for this professional by using DigiTech as it made procedures more simple and improved effort and reduced effort. For example, from using a simple Excel sheet to integrated systems where all information is connected. Another specific work practice example is given to highlight the improvement of the	The professional indicates that he learnt his work practice through two major mechanisms. The analytical part as he indicates, he learnt by self-education and the human engament part through other people and engaging with them. The technical skills if he runs his own project he has learnt	For this professional, Digital Technology in work brings with a required understanding because the results are unpredictable and emerge in practice and to solve that, it requires both an understanding of the computer system as well as the task itself. Learning the specific skills unique to working with digital technologies are focusing on troubleshooting and systems analysis, of which both are learnt during school by trial-and-error when spending time with other students and elaborated on in work. In that	The professional selected eight knowledge areas required to execute this specific practice of which 3 disciplinary knowledge areas, learnt in school, 2 science oriented also learnt in school, and 3 social science oriented learnt by trial and error only. During the interview the professional elaborated and explained that he learnt his admin by trial and error because he never learnt it as part of his engineering studies. The disciplinary engineering knowledge, he	The professional selected in the survey a significant number of skills required for the current practice and reconfirmed this during the interview. Most skills can be found in the general direction or social science direction. No engineering specific disciplinary skills were selected but he explains that he needs a little bit of everything to inform his daily work. Reading on a work-skill of critical
Example of quotes or survey answers supporting the above discussion EP1											*And for that specific Big Data and analytics what you selected.... is that .... are you using Microsoft*	*Decisions can be made on financials and contractual decisions based on your level. My*	Power issue, Advancement of work but enhancement of human skills	*I will explain what it is to me. Digital technology is what I believe is where they've taken an analogue procedure*	*So, the analytical part of my general work I've learned by self-education. And by trial and error.*	*Because digital technology doesn't always give you the output you want or doesn't work exactly as you thought it might. So, you need to understand why it is not doing*	*Yes. Because when I had schooling. I never had lessons on administration and management. It is by taking up responsibility during my working career.*	*That might be ... I wouldn't say highly skilled. We need a bit of understanding of everything to be able to give a concise*	
Key-terms/sentences that come up for me																		
empirical case of a shared practice of 'developing plans' among the engineering professionals in my study:									5 principles of engineering practice					learning for professional practice				
Empirical case EP3	**Engineering level**						**practice**		**1. knowing in practice**	**2.socio-material**	**3. embodied/relational (doings)**	**4.exist and evolve in historical and**	**5.emergent**	**Learning for practice**	**Future learning needs for practice and DigiTech**	**Learning individual knowledge for practice**	**Learning individual skills for practice**	**Conclusion**
empirical case EP3 is a female and full engineering qualified (graduate level) junior electrical engineer working in a larger engineering construction firm, based in a well developed work context and operating in various countries across the globe.							Develop plans and estimation of costs for the installation of systems, utilization of facilities and construction of structures is for this professional understood as making a design based on client requirements, assessing the site location to see the specific context, develop plans and estimate costs for the required project. From there onwards, the plans are developed and written up in a report. The professional sees the practice as a process with the earlier listed specific steps involved. The professional sees it as a process because the practice is in practice changing, based on colleague and client feedback.		The human actors involved in this practice where the professional is a member of are ranging from clients to direct team colleagues and the project manager. Roles in the network are ranging from project manager, mechanical engineer, senior electrical engineer, an advisor who is more involved with the client directly, the fire engineer, the structural senior and junior engineer which are perceived as the rest of the team. Nonhuman actors involved are a lot, extensively and ranging from electrical engineering tools, disciplinary specific to digital technology tools and processes. DigiTech's are focusing on drawing the designs to inform the decision making and get approval for the final execution of the project as	The practice is embodied in time because it takes up an essential part of the practice of this professional, ranging from 70% of time spending on this practice to 40%. The level of decision making for the professional being a member of this practice is limited in the sense that specific allocated tasks are within full decision making capability but in practice, the decisions are made with her colleague and senior engineer together. The professional perceives the changes by DigiTech as something that automates human processes and enhanced human skills with time improvement and time that comes free to spend on thinking about other things. The impact is perceived as enabling a deeper and	The practice is specific to the requirements of the client and the site in where the project item has to be placed (electrical components) and is thus part of a larger localised and context specific project. The engineer working in this practice has an office on site, with the client.	The practice seems to be emerge as the professional indicates that it is constantly changing based on others input and in practice.	The professional indicates that she has learnt most of her basics of the work practice in University and built forward on this base in practice. The theoretical part, she perceived is what is learnt in school and application in the real context is what is happening at work later on. She perceives that she learnt a significant part of her practice from senior engineers as well as work-based courses provided by the company as well as suppliers. She sees her learning as a combination but preferred is learning from other engineers because they know how to apply theoretical knowledge into practice.	One different skill was selected in the survey as being essential to work with digital technology, operations analysis and for the professional this is learnt in work learning by doing and improving when the result is there. Learning from a colleague is indicated as important in this sense. One different knowledge areas was selected in addition to disciplinary and technical, design knowledge required to work with DigiTech, telecommunications learnt by trial and error because it was limited in schooling. Working in specific context with simulations is learnt through supplier training, from a colleague who is helping her out as a role model.(mentor)	The professional learnt most her practice knowledge in school except for design because she learnt that while working by designing specific solutions, improve them and implement them.	The professional selected in the survey about 10 skills required for this work practice, ranging from general skills such as writing, reading to more technology specific skills such as equipment selection and technology design. Her perceived learning for work was rather various with different modes such as school, work, reading books, and using intuition plus colleagues. However, the focus in the interview dominated on learning from experience in practice and from colleagues at work. However, she admits that she has a strong foundational schooling base, she also indicated that learning in practice the tricks is essential as with an unpredictable time pressure playing part.	**She is learning for work in terms of skills by learning from a colleague because then she has all the info in the right context**
Example of quotes or survey answers supporting the above discussion EP3							*My understanding is that in my context, what I do is that OK we have a design. So we have to make a design. What I start doing is... a hum trying to See the site because the client always has a site selected so I see the site and see how I can ... How many switch rooms or switch boards I can fit there. A hum.. Therefore.. a hum.. how many*		*so...there is a project manager who's also the lead and mechanical engineer. Then there's the other mechanical engineer who's helping the lead mechanical (interviewer) yeah...Then there's the lead electrical engineer who is not it's not me it's senior electric*	*Yeah. Okay. So, it depends. Because I say this in the context of me being this designing. The 50 percent of the 75 percent of our project. Yeah. When that project like when that's the case and I'm designing and I'm in the process of designing then that takes at*	*it is in the office on site. I'm not I'm not that much on site because I am On site but I'm really in an office. I might go to the construction site twice a week a couple of hours to make an exception. [cannot identify the word]. Things like that' (EP3)&	*OK. So because you explained that you are going to the site and then you analyse how many switchboards you can implement and the estimated costs. So those are the specific steps in it?* *EP3:Yes. But if it's always a process because. Well we develop some plans*	*So, I learned all the basics in uni. (interviewer) Yeah .... So. So. So for example the fog levels and short circuits and all those things I learned that in Uni. Like the theory. (interviewer) Yeah .... But then in... I learned everything else, like how to apply it. How*	*uhm. that is in work learning INTERVIEWER:In work learning. Okay. Yeah. And would you learn that by doing something and then finding out that it can be improved, or would you have learned it from a colleague or senior or both Or? EP3:I think both. Yeah.' (EP3)& 'telecommunications? Yes. I they have some but not much but yes, ha-ha some foundation but also didn't work.' (EP3)&*		*Well I guess the reading comprehension has a lot to do with practicing like more Understanding and... well yeah I have read a lot (ha-ha) in my life. I have read a lot of papers I've read. Yeah. So Of course you get to comprehend a paper you would need to Practice like. It's not usually a paper it's more than a hard thing to get. (interviewer)*	
Key-terms/sentences that come up for me											**Positive impact of DigiTech, Time reduction, Profesional responsibility changes, Quality**					**Learning in school foundation, trial and error in job.**		
empirical case 4									1. knowing in practice	2.socio-material	3. embodied/relational (doings)	4.exist and evolve in historical and	5.emergent					
empirical case EP4 is a male and full engineering qualified (graduate level) managing director working in a larger engineering construction firm, based in a well developed work context and operating in various countries across the globe.							Prepare reports and document project activities and data is for this managing professional perceived as a record that captures the recommendations for problem, specifications, styling or any construction drawings. The work practice is seen both as a goal and a process as the creation of the deliverables is a process and the goal is to deliver them on time and within budget. The		Human actors involved in the practice are roles such as technical director, project leader, specific engineering disciplines and sometimes even a package lead if different engineering disciplines in a large project have to be leveraged.Non human actors involved for the managing	The practice includes for this professional member a high level of power as the professional is the final decision making party on behalf of the own business and refers to engineers involved in his team, having own autonomy and depending on the project a high degree of decions making	The work practice for this managing professional is mostly bound to the local office environment but travel to clients for external meetings do occur on some projects or involvement of clients in he construction project means meetings on site and as such, the context defines if the site	The practice is perceived as having changed for people working in this practice underneath the managing professional by digital technology but not necessarily replaced human skills as they are still required for work. When work is automated, it can happen that other work develops for those professionals and that does not	Learning for work in the context of digital technology from the perception of this managing professional for engineers working in the same practice would be depending on their experience. If they have pre-existing knowledge, but the process becomes more detailed and technical, the work-based learning can offer something that aligns with	If people need to learn working with digital technology in their practice, it comes down to self learning and occasionally some supplier let training to learn the software. The preferred route is to look first into the in-house training options before external help is sought, in which case they support the request if it is in the benefit of the company.	In this work practice, the managing professional selected five knowledge areas required for this practice, ranging from disciplinary (1) to social science (4) knowledge, mostly learnt by either work-based training or trial and error .Cross disciplinary knowledge such as finance is perceived as something more suitable to go back to a formal schooling system and do structured schooling while supplier led training can offer something that aligns with	The managing professional selected for this practice 7 skills required to execute the practice, all general skills and learnt in different ways such as school, training, trial and error and using intuition. When elaborating on the selection of time management, it is something perceived as something picked up at work or during school and not necessarily taught in school. When
Example of quotes or survey answers supporting the above discussion EP1							*If I can take both to create those deliverables and as such is it a process but the goal is to be able to deliver them on time and to budget.' (EP4) & 'Uhm. yeah so. Probably in terms of financial that would probably be more an internal thing that may not actually find its way to the report unless there was a specific require or business case that may be provided*		*Very high autonomy depending on the project. There may be a technical director involved , a project leader ,[we are a physical force in the] for a specific engineering activity and there may even be a package lead depending on the size of the work that have*	*Revit is used predominantly for Modelling and documentation of the services and structure. Occasionally 'Okay '. And while, while I think there are some things we can do in there b ut we generally that we do the modelling or simulation outside of*	*Most of the time it would be in an office environment , a hum. Occasionally though there would be a lot of external meetings with clients or they get involved in the actual construction activity on that will be based on site.' (EP4)*	*And I think there's been advancements it's been advances in digital tools and people have maybe some younger graduates younger engineers have definitely got upskilled, [although [we use these tools [to get to work,[* *EP3:So in some they're in some cases that can replace a dedicated drafter or*	*It depends on what it is [is a computer] to learn. If it's a branch of that Of something that a that they have a reasonable knowledge about but just maybe a bit more detailed and technical would be done here. If it is something new. You don't have*	*We offer some in-house training but largely it's self-learning. And then there's just sort of support for people who maybe [need]that software. But mostly it's sort of self-learning in the software environment. And '.. uhm. there is maybe the occasional [report] for external training that's [anywhere]' (EP4)& 'Yeah. Some of that stuff we do have in-house and we would ask them to look at the in-house offerings first. But if there was if they had*	*Yeah.I guess it depends. It gets depends on the course. Some. Manufacturers offer Training that's aligned with the industry but in some cases I might want to go back to a more structured school system like that might teach more around some finance rather than engineering or something like that.'(EP4) & ' and generally, unless I want them to be considered an expert in something and you know*	*But again in terms of time management it is not something that's necessarily taught in an office environment or in a consultancy as part of a... It is generally something that you pick up maybe not necessarily through high school or [wherever but that] school but maybe through university. A good thing in terms of picking up and making sure we've*	
Key-terms/sentences that come up for me										low level engineers use modelling, high level use computational design, professional responsibility								
empirical case of a shared practice of 'developing plans' among the engineering professionals in my study:									5 principles of engineering practice					learning for professional practice				
Empirical case EP5	**Engineering level**						**practice**		**1. knowing in practice**	**2.socio-material**	**3. embodied/relational (doings)**	**4.exist and evolve in historical and**	**5.emergent**	**Learning for practice**	**Future learning needs for practice and DigiTech**	**Learning individual knowledge for practice**	**Learning individual skills for practice**	**Conclusion**
empirical case EP5 is a male and full engineering qualified (postgraduate level) sub-site agent working in a larger engineering construction firm, based in a medium developed work context and operating in a local context only.							The practice of develop plans and estimation of costs for the installation of systems, utilization of facilities and construction of structures is for this professional is understood as given from the other side of a project what means that calculating based on the prices of suppliers and other parties happens as well as planning based on the time effort for them [team] directly. The professional sees it as a process of which the procedures he is going to use are planned for, he has to see if his estimated costs are within the budget and as such, also has to determine whether of not he is making money. Inclusions in the practice do entail general resources, time, material prices, labour prices, accommodation to estimate costs. The practice is a fair share of this professionals work as he spends most of his days on this practice, depending on the stage of the		Human actors involved are both clients, who have a big impact and appearance in the practice, local contractors, suppliers and people from the project team directly as well as community officers who control alignment of the local regulations with the execution in the project. The work roles involved from the team directly are more significant at the beginning of the project, such as senior site agent, contract manager, operations executive, himself as a subsite agent, te site engineers. The practice is mediated by a large and complex network of human actors but also nonhuman actors. Nonhuman actors are significant for this professional in this work	This practice is relational and embodied as it includes for this member of the practice a high level of power as he has 50 to 60 workers underneath side directly he is leading. On behalf of his business, he is the operational leading party. He sees the operational construction workers as a different kind of people which he gives limited autonomy in the execution of their work. The professional perceives DigiTech in this practice as an enhancement of human skills and an advancement of work at the same time as it helps people to do their work with less effort and time.	The work practice for this managing professional is not mostly bound to the local office environment but takes place both on the construction side directly and in his office environment on site with the client. So this site is specific for the duration of the project only after which the environment may change as well as the localised context, regulations and so on. The practice is contextual mediated by regulations to include workers from the communities and therefore bounded by these localised context features. If the practice moves on to the next location, the context might change again.	Although the professional can only refer to the last working years to compare changes of the practice with, he sees that the practice has changed in the way that previously manual work can be done automated now. The practice has changed in the way that time has improved and the effort reduced although in essence the steps involved stayed the same but the way HOW changed.	This professional as member of this practice believes that the best way to learn this practice is to spend time with a more experienced professional and observe them (learnt about a week what will give them the necessary insights. If they come from another company, the process might be easier as they have pre-existing practice knowledge but just need to transfer this to a new work context. It can be working with a different kind of software, the work process stays in essence the same but the way towards this can be different and needs to be learnt. This professional acknowledges also that he might learn from someone coming from another company about different ways of	This professional has not selected any of his skills and knowledge to work specifically with digital technologies in this practice differently to the practice itself. The same, although less skills were selected, mostly in the area of general skills and management and programming (learnt by trial and error) as well as more knowledge areas such as social sciences and 3 technical. Working with digital technologies is what he learnt in school but because he had access to the resources but he thinks that age plays and motivation plays a role in learning this. He acknowledges that people in lower position might learn better on site at work but at the same time he argues that the reason why they have ended up there is also motivation and working hard in school to reach that level.	In this work practice, the managing professional selected five knowledge areas required for this practice, ranging from 3 disciplinary knowledge areas to 2 social knowledge areas. The preferred selected learning mode was either from a colleague at work or in school and he elaborated that what he learnt was from his mentor in practice. How to really do the work. He uses his school learnt knowledge to some extend but this is not what he sees as daily, he rather sees is as a foundation from where he builds forward in practice. However, he refers that the technical part of his work was what he learnt in school but this is not the focus of his work anymore because he is not directly performing engineering work himself.	This professional sees this practice as highly skilled because he selected 18 skills in the survey. When elaborating on in the interview, he refers to people skills as essential to execute this practice because this practice entails dealing with a lot of different kin of people, all with their own agenda's. For example, the selected skills ranged from technical (5), to social (3) to more general skills such as critical thinking for which he indicates that by using intuition and calculating in advance behaviour of others and consequences what might happen at work due to other happenings. Quit a lot of this has been learnt from his senior who appears to me as a mentor and taught him the practical tricks to deal with unanticipated problems. Another general skill example, such as reading and listening, both also connected to people skills, the basics are learnt in school. Time management is more likely to

Example of quotes or survey answers supporting the above discussion EP5		*Yes like not really develop.... you develop. yes you can say that but you say like construct. construction industry is to build something like maybe for example to [Costa] to build a wall . you know'(EP5) & What is it that is going to take you to do. Like general resources, your time , the price of the material , price of your labour. Those types of*		*so the client is also around yeah. (Interviewer) 'Yes '. and then we just basically spend a lot of time with the client. Try to find out what they want and things like that.'(EP5) & 'Yes yes. Because he's the one that we need to please at the end of the day' (EP5) & 'It was*	*Look it's not that most people .... like I wouldn't say that people sit in front of a laptop like me. No they are the people on s item doing the work' (EP5) & 'And machinery and the foreman, engineers those types of people' (EP5) & 'And I prefer I let you guys*	*Depends when you say office or site because my office is on site with the client. INTERVIEWER:Ok, hahaha EP6:So yeah because you can say it is on site with the client '(EP5)*	*I was at campus five years ago and the way my lectures did certain stuff originally? (interviewer)' Yeah' we can do it we can do it on the laptops really with programming and nobody was teaching us something like that. Not that they haven't brought that up in an campus .On varsity.*	*OK new. Someone new comes in I say ideally what should happen is they should spend about a week or so with me learning what I do and what procedures and watching ,obviously if they've done the job before then it's just basically a hand-over, you*	*Well ...in my role, I learned it in school in high school and also I was afforded that opportunity ,you know to go to a good school who had all of the technologies and stuff and my parents bought me a personal computer so I could you know practice further and you know better myself. Yes but some other people on site, I would say.. like this lady that I just spoke about she.... she knowns here and there but I would say She learnt her stuff on*	*I would say what I learned. what I learned, especially within the past year most of what I'm doing now I learned I on site from my manager. So obviously I apply whatever I know you know the basic program Excel and PowerPoint and things like that. I don't learnt it on site when I knew that stuff but like te really learn to do things, that stuff I learned from my manager knowledge but the stuff*	*about their strength to communicate with. People skills . Because you need to speak [?] with a client and you now..... he knows a lot of other people in that area. Because we are not from the area. I mean you know you can get to know these people and things like that.... community engagement because you need to hire from the community to do your*	
Key-terms/sentences that come up for me				basic nonhuman actors for information accessing, nonhuman agency and power. Professional			the how changed				mitigating to prevent power/control loss,		
Empirical case of a shared practice of 'preparing reports' among the engineering professionals in my study:			**5 principles of engineering practice**					**learning for professional practice**					
Empirical case EP6	**Engineering level**	**practice**	**1. knowing in practice**	**2.socio-material**	**3. embodied/relational (doings)**	**4.exist and evolve in historical and**	**5.emergent**	**Learning for practice**	**Future learning needs for practice and DigiTech**	**Learning individual knowledge for practice**	**Learning individual skills for practice**	**Conclusion**	
EP6 is a male and full engineering qualified (graduate level) mechanical engineer working in a larger engineering construction firm, based in a well developed work context and operating in various countries across the globe.		Prepare reports and document project activities and data is for this operational professional perceived as two options of a report, where the one can be a technical report with technical specifications about a mechanical feature or process and the other one can be a design specific report in where the mechanical component is part of a larger project and the aim is a quality report. The professional sees this practice as a goal because in the end, he needs to align with deliverables in both cases of a report and that is his goal. Activities in this practice are focusing on information components in which calculations take up a fair share and assessing options is a key part for the preparation of what goes into the report. Initially a site visit is done where photo's are taken, reviews and sometimes another site visit before a report is made. The practice is a fair share of this professionals work as he spends on average 2		Human actors involved are both clients, who give the directions for that what they need to find out and a smaller engineering team of 2/3 with a leading entity. When it concerns the technical report, it includes often a team with only mechanical engineers and where it is a design report, it may include different engineering disciplines such as electrical and hydraulically. The nonhuman actor selected in the survey was only CAD for 80% but in the interview, it comes forward that more various technologies are involved in the practice such as excel, power bi, calculation and simulation software. In the simulation he runs a worst-case scenario as a baseline for his design and it is rather a	Relations with the clients who give clear directions for what they need is significant for the practice of this professional. The professional sees the enhancement of human skills by DigiTech and at the same time thinks that the engineering skills required are staying the same.	The work practice for this professional is mostly bound to the local office environment and the regular site visits. Thus it takes place both on the construction site directly and in his own office environment. The practice is shaped by both reverting back to previous practices and also by gathering data first.	The work itself has not changed but the completion mode has emerged into a digital format. In that sense, the work became automated from a manual variant. The reduction of less effort and time was essential in this process. The work in-company has emerged to streamlined processes and reduction of effort and time by allocating tools that makes the practice easier such as direct annotations on photo's that are captured for a report and as such, the final report can be made on the go.	Learning for practice takes place in practice by literally being guided by another worker and do the steps involved yourself. For example, pushing buttons in a software program.	Two out of 5 skills were selected differently specifically to work with digital technologies, namely, installation and troubleshooting. The professional explains during the interview that general skill such as critical thinking are easier to implement to work with technologies but other things could develop more scope. For example, he refers to be able to programme to make things much more easier and reduce more time. For specific skill sich as troubleshooting and installation he refers to the fact that for working with digital technology the first times, time can be more and you need to learn and re-learn how to deal with the technology.	In this work practice, the professional selected 3 knowledge areas required for this practice, ranging from 2 disciplinary knowledge to 1 social knowledge, learnt by books, colleague and trial and error. He explains during the interview that he learnt his administration and management for 100% on the job from his colleagues. He also states that his practical knowledge of engineering and construction was what he needed to apply in a real world context, the practical kind of job knowledge what is thus learnt by doing it in practice. He also states that software specifically has led to fundamental knowledge in the sense that it automates specific manual calculations.	The professional selected only a few skills, 4 namely of which all were general skills as required to execute the practice. These skills we either learnt in school or during work-based training. He elaborated in the interview that work-based training includes for 60% learning from colleagues and 20% internal and supplied led . He also argues that he learnt quit a lot of his practice at school, what he states is not common at all for engineers and he still uses on a daily bases the theoretical part of what he learnt in school. He refers that the day to day practical work is not what he has learnt in school but only the theoretical part.	
Example of quotes or survey answers supporting the above discussion EP6		*Sure. So a lot falls into generally two categories. One would be like preparing technical reports. So it might be someone asking to view the performance of the building or a specific bit of equipment. And the other one is where we have specified equipment to meet our design plans. They could be kind of working in the development*		*'Usually it's both common to work in a team of two or three with one person leading.' (EP6) & 'uhh. 50... 50 50 (interviewer)' oh ok 50/50' yeah 50/50 usually . yeah yeah' (EP6) & 'I would say generally a mechanical engineer but where rare i ts the technical project it is*	*Usually the technical parts are components of projects or reports from their own, that will be the client. A client will ask us to do a report INTERVIEWER:okay. So. So your relationship with the client is that the client gives you like*	*Usually this would be in the office but the sub task of going and doing a site review is up alongside the site'(EP6) & 'I would say, probably on a constant basis.' (EP6) 'I think we would typically revert back to previous problems but mostly it's gathering data first'*	*yeah. That is Absolutely. But I guess uhm the software we're using is quite. I don't say cutting end but I guess probably one of the more sophisticated software's where there are more simple software's and they've been used in the industry for At least 10 years. But.... absolutely! the*	*Generally. We have a sort of internal training. So look at other staff made and this is what you're doing in a scenario. But I would say the majority of that upskilling is done by literally someone sitting next to you and saying 'press this' then press this'*	*No!! ...But I think they are some of the easier things to implement. (interviewer) 'OK'. So I actually think that there's a lot more scope to do things in other areas. It just is extra more effort ' (EP6) & 'eeff... uhhmm....I just a little bit.... Just because in my experince [of being] that some of the processes have required re-learning how to do things. And so that software, like the troubleshooting because it's the first time you use some of this*	*Yes it... Yes. Yeah so it is actually that what I was thinking was that the software I was talking about we actually did those calculations by hand. (interviewer) 'Yeah .' And then , see that led to fundamental knowledges ,software has supplement that by using software .' (EP6) & 'No, I would say that is a 100% on the job INTERVIEWER:On the job. OK. Yes. You select*	*I would say probably. A 60 percent colleagues and then 20 [percent to ...]' (EP6) & 'So, I would say, the majority of it And that's not true for all engineers but the majority of the tasks that I do on a day to day are actually part of a university course. INTERVIEWER:Okay so you 've learned quite a lot of your actual practice now in*	
Key-terms/sentences that come up for me					less administration due to DigiTech, same engineering skills		work became easier, time reduction and effort is less				school based foundation. Workplace application for practical, positive perceived theoretical university foundation		
empirical case of a shared practice of 'preparing reports' among the engineering professionals in my study:			**5 principles of engineering practice**					**learning for professional practice**					
Empirical case EP7	**Engineering level**	**practice**	**1. knowing in practice**	**2.socio-material**	**3. embodied/relational (doings)**	**4.exist and evolve in historical and**	**5.emergent**	**Learning for practice**	**Future learning needs for practice and DigiTech**	**Learning individual knowledge for practice**	**Learning individual skills for practice**	**Conclusion**	
empirical case EP7 is a male and full engineering qualified (postgraduate level) structural engineer with operational managing responsibilities working in a larger engineering construction firm, based in a well developed work context and operating in various countries across the globe.		Prepare reports and document project activities and data is for this managing but technical operational professional perceived as developing a design report which includes a lot of drawings. In initially sees the practice as the end goal, his deliverable of the final report as per request of the client. The investigation with the information that comes in the report proceeds the final report although not all preparation finds it way into the final report. The types of report do entail technical specifications, drawings and reporting itself. The technical specification and drawing report finds it way to a subcontractor who has to build according to the exact same specifications and drawings provided in the report. The final report is more for the client and internal use as well as authority approvals. The practice is later in the interview seen as a process and as an end goal because it is a journey to get to a point		Human actors involved are both clients, who give their specific directions, then the project director, the technical director, this professional as managing structural leads a team of 11 engineers who also have drafters underneath them. Non human actors involved are focused on digital technology software.Non human actors selected were BIM, Big data and CAD with 70% of this work practice. He elaborates that the models and checking them is the core of his work and the deliverable they produce is based on BIM. The big data is focusing on making so much information manageable and have the data to manipulate and make sense of it. On the site of simulations, he uses	The professional is physically checking the work of the human actors working in his own operational and technical team. He is personally involved to make sure that what they have done is checked because it can have major consequences such as safety and money. Another aspect is that he is aligning their work with different disciplines to make sure all is coordinated together. He sees himself as very involved in the practice and has concerns about people who cannot see the bigger picture of a project and only use their own tunnel vision.	The work practice for this managing but operational professional is bound to the local office environment behind a computer. However his personal work was physically bound to one place, he had to coordinate for this project with other teams in other locations across the globe and thus that part of the practice, although not embodied was not locally bounded. This brought some challenges as the culture, the way of communicating, the level of skills and processes were different in those offices. When asked if the level of skills between offices was significant, he argues that the level of skills within an office was different.	The work has under the impact of digital technology changed in the way that more complex is possible. Boundaries can be pushed and it is challenging what is possible in practice. He sees that digital technology has both completely enhanced human skills but at the same time advanced his work.	Learning for practice takes place by doing it in practice and the ability to upscale oneself. Being proactive is essential and being able to keep up is essential. If you cannot learn , you cannot keep up.	The need to work with more sophisticated technologies is essential and one need to upskill to be able to work with these. Not complying means going out of routine, more into a manager role but even then it is the question because you have to understand the processes to make decisions. Specific skills to work with DigiTech focus on programming, systems analysis and systems evaluation, learnt by using trial and error on the job. The knowledge is similar to that selected in the work practice without connecting directly to DigiTech. He sees understanding how things work as different to mastering working with them. Programming is in his view essential and he sees DigiTech as part opf our nature that we cannot ignore to move forward.	Work knowledge that was selected in the survey only included 3 areas, two social, one disciplinary. Elaborating in the interview he explains that most is learnt on the job because only then you learn how to deal with people. Knowing how to approach people and meet their needs is essential in his work practice and is something you develop over time in doing.	The skills required to execute this practice were 6 selected, all general skills and learnt by either trial and error or intuition. In the interview, he elaborated that the things that they are doing are so complex that one need to be able to analyse a situation and quickly come with a solution and then test. He argues that experience is essential because the practice emerges in practice and these kind of things cannot be captured before they happen. People that can not make the move to quick responses are not very aware of their practice and difficult to work with. If they take to long to think, time is money. For example writing is learnt by using intuition, building forward on what is learnt in school. The process has became synthesized to that learnt in school, references are only used in a straight forward manner and bullet points preferred above full sentences. Interesting is that this professional selected problem	
Example of quotes or survey answers supporting the above discussion EP7		*So as an example. My latest project was. Essentially issuing. Six-hundred drawings and documents and then another six reports, so about a thousand-five-hundred pages of design report. So it's ...that's what I measure as; Prepare reports and documents for project activities and data because that is our deliverable. That's what we get paid for!'*		*Oh yeah. So.. OK... So.. uhm... I'm in the structural team so I'm a structures lead. So it's got one technical director above us. (interviewer)'hmm'. Obviously, we've got a project director above that. So Project Director, technical director, me. (interviewer)'Yeah '.*	*Yeah well, if you've got if you've got 15 people working for you... you need to make sure you check all their work. Not all of it but at least. Up to a point where you are happy. That's not wrong. INTERVIEWER:So what are the consequences if you would not do*	*Correct . Not just perse because of the technical challenges that's on... So I can't just hand it over to anyone. Yeah, I sort of micromanaged. The eleven people down there that they were working with other people. It was sort of small little teams that are*	*I would not, you can say. I wouldn't say it's made the work easier. It's made the more complex doable. So, it's not... it's not made my work easy. It actually made it more complex. And it just allows you to do more complex buildings. That's what it is.' (EP7) & 'correct. You can push the boundaries*	*I would think... yeah... the ability, the ability to upscale yourself is probably the first thing.' (EP7) & 'Or just being proactive, being proactive probably. So the best guys I work with, or the guys I want to work with, is a guy that. I've taught once, just once!' (Ep7)*	*Yeah but it. I mean even if you look at the BIM, that's probably the biggest shift in our industry in the last five years and it's now the norm. In five years' time if I cannot programme, you're redundant. I am already seeing that. But in five years you will be redundant if you haven't got the programme skills. (interviewer) 'Yeah '. Especially in my industry and the main, BIM is already ...if you cannot do BIM, you're already redundant. Then you've got to be*	*Hmm, well we did some management courses but I think.... uhm. where you learn the most is still on the job. I think the biggest thing about management is learning to deal with people. '(EP7) & 'that doesn't time with the technology.... that it's... it's ...it's all about ...it's all about being able to meet people and knowing how to approach. you change your approach with people' (EP7) & 'it's something, that*	*I think it ties in with the things we're doing are so complex. (interviewer)'Yeah' you got no idea what the right answer is when you start. (interviewer)'OK'. so that's where critical thinking is pretty important. So you need to be able to ... Analyse the situation, propose a solution and check if the solution works. (interviewer) 'ok'. Then you cannot*	
Key-terms/sentences that come up for me									DigiTech part of our nature		Unlearning academic skills, learning in practice, professional judgement		
empirical case 8 (Digitech Supplier)													

APPENDIX M-INTERVIEW CODING PROCEDURES

THIS SECOND ROUND OF CODING WAS THEN DONE BY FOLLOWING 3 STEPS.

In Step 1 of the second coding phase, all interviews were initially data-driven coded, paragraph by paragraph and with a similar approach in content analysis in where the focus on sentence or paragraph is used to increase the meaning-making of the analysis (Wilkinson & Birmingham, 2003) . According to Wilkinson & Birmingham (2003, p. 68), I had to code the interview content into words and themes and test to see "whether or not they accurately represent what is being said". This content analysis approach was also referred to as thematic analysis based on the search for themes in the text (Wilkinson & Birmingham, 2003). The approach fits well with sociomaterial sensibilities since the data is approached with an open mind (Gibbs, 2007) as opposed to strict pre-existing coding schemes, the possibility for emerging themes in the data was left open and it allowed to move beyond frequency into occurrence and relationships. The categories that were selected for storing the codes that were developed were selected based on the three research areas of concern, the survey results and the literature part and helped to structure the coding. The approach that was followed can also be understood as a form of holistic coding because a single code is applied to larger parts of the data to capture its content and context and is, according to Saldaña (2013, p. 142), well-suited for beginning qualitative researchers. This holistic form of coding is also understood as an exploratory method although a general idea about what to investigate exists (Saldaña, 2013). This first approach is similar to the method of initial coding that is often used in grounded theory research but for this, at least 10 interviews are the minimum associated qualitative data (Saldaña, 2013, p. 104) which was not the case here neither was the grounded theory selected for this thesis.

Step 2 of the second stage of coding and analysing. In this step of the coding and analysis process, the codes were further reduced/amended, based on coding similarities and differences. They can be associated with the method of evaluation coding which can consist of multiple methods. The method was identified as suitable because it is applied to participant perspectives, mixed methods, case studies and allowed for cross-case and thematic analysis (Saldaña, 2013, p. 119). For most of the nouns, a form of descriptive coding and "elemental coding" was applied (Saldaña, 2013, p. 59). For instance, the specific forms of digital technology or the different role players in the work practice in where was sought for who the members of the practice were and what is used in the practice. For any actions of *actors* that were sought in the interview transcripts, conceptualised as performances, the

coding technique is associated with “action” coding (Saldaña, 2013, p. 96). This process was meant to identify the performative actions of the *actors* in the practice. The last coding technique was the assignment of “judgements”, which is an effective method (Saldaña, 2013, p. 119), to the interview data. This technique was used to make the professionals’ perceptions and attitudes towards working with digital technologies visible.

Step 3 of the second stage of coding and analysing. When all coding had finally been reduced to 38 major codes under 6 major categories for clear organization, a framework matrix from all coding references from the 7 interview cases was generated in NVIVO. The codes were visualized in a framework matrix “to see both trees and forest”(Saldaña, 2013, p. 199), which gives a holistic view and was used to identify patterns and evaluation of results to proceed with meaning-making by asking questions about the data to find this meaning: What? So what? Now what? This meaning-making was also operated by adding “is” or “means” to codes (Saldaña, 2013, p. 205) and developing hunches for concepts. I transferred the framework into MS Excel and coloured empty cells to identify outliers and possible coding errors which is shown in the table below. In the table’s first column are the codes depicted and the colouring is connected to the paragraph of the interview part of the engineering professional connected to the coding variable. For these incidences, I read again the respective interview transcripts and queried to see if the respective code was applicable to any of the data in the interview. This resulted in a new and final framework matrix.

Figure 41.Visual depiction of coding framework to check coding practices

A : Automating work							
B : Changing work (neg.)							
C : Changing work (pos.)							
D : Changing work outcome							
E : Changing work process							
F : Data action							
G : Design action							
H : Financial action							
I : Other digital action							
J : Outcomes and solutions							
K : Simulation action							
L : Digital impact negative							
M : Digital impact positive							
N : Digital technology intensity (use)							
O : Digital technology nature							
P : Digital technology type							
Q : Human capabilities for digital							
R : Human knowledge for digital							
S : Human skills for digital							
T : Knowledge							
U : Skills							
V : Learning dependencies							
W : Foundation. Basics							
X : Knowing how							
Y : SBL							
Z : SL							
AA : SOL							
AB : TBL							
AC : WBL							
AD : WL							
AE : Professional autonomy group							
AF : Professional safety							
AG : Professionality							
AH : Work actors							
AI : Work doings group							
AJ : Work emergence							
AK : Work practices 2x							
AL : Work purpose							

APPENDIX N- AUTOBIOGRAPHICAL REFLECTION – PERSONAL DEVELOPMENT

Undertaking the PhD program and the development of the current thesis was both a valuable professional learning experience as well as a significant personal development story. For the professional learning, the improved understanding that I developed about the nature of qualitative research with all its features and messy subprocesses, was significantly different than the academic research undertaken in my Master of Education. The Master of Education has provided me with valuable insights into the nature of practitioner action research, but the sometimes complicated hierarchical and also cyclical research process of the qualitative research part undertaken in this thesis was completely different. From a practical point of view, I have learned, for example that using empirical data from participants in industry can be a timely process that most certainly demands significant time allocation. I also learned that certain strategies associated with improved response rates of participants do not necessarily align with those applied to improve validity and trustworthiness of data. For instance, the group-administering was used as participants were invited by their company which may have resulted in respondents feeling personally involved and as such may have contributed to increased response rates (Wilkinson & Birmingham, 2003, p. 8). At the same time, it could have resulted in the participation of specific group of professionals that felt attached to their company and responsible which may give different results as opposed to when randomly selected professionals would have been used. Therefore, my starting view about a research process as being a strategic and pre-defined structured process, has changed to a view, that research can sometimes be unstructured despite careful planning and a more flexible approach is required from time to time. Especially the latter point has proven a point of challenge for someone with a planning and perfectionist nature, but I believe that I succeeded to mitigate these challenges over time.

This program has also provided me with improved insight into my own professional beliefs and position in the field of education. These have led and could potentially further lead to changes in my own future professional practice in education. For example, I would adopt and advocate for more diversity of 'philosophical approaches', since I have now more awareness of their possible impact on learning practices, but also teaching and research practices. Furthermore, the techniques and strategies that I learnt on the way, and the skills that I developed during this PhD program, will be of enormous importance in my further career. For example, considering my research practices, I improved my understanding of the careful development and alignment of all research frameworks before data collection since they have consequences for the selection of appropriate methods and instruments. However, at the same time, I also recognize that applying flexibility to the original approaches and design will somehow tactically emerge in research findings that would otherwise

never have been emerged. This is one example of where my worldview has changed from one 'truth' to a possibility of multiple truths or an acknowledgement of the existence of multiple ontologies.

Lastly, in a personal way, I have developed my thinking about learning from one that could be best described as cognitive-behaviouristic of which my thinking was not aligned with how I executed my professional practices in education. To the development of thinking about learning which aligns more with how I performed my professional educational practices and my personal beliefs. This thinking can be best described as one that aligns with a practice, that opens more theoretically to a wider plethora of f*actors* and impacts, such as understandings aligned with those of sociomateriality. Another challenge was that I had a lot of self-acquired knowledge about digital technologies and their capabilities, but a lack of strong academic reference limited my discussion of this previously.

To conclude, the program has been supportive for the development of my English language skills. I started with limited academic English language writing skills and a deep insecurity about my English language skills and I have improved these significantly during my PhD program. I sometimes even improved them over days as I found out by checking my own writings after a few days and finding my previous writings limited. I acknowledge that there is still a long road to go to become fully confident and fluent in academic English language writing but every step counts in this process and certainly the 200.000+ small steps I took here. I am excited having made the first steps towards becoming a social science researcher and cannot wait to put my skills into practice and improve them in the field of academic research. My next step is to generate journal publications from the exploration I did in this thesis of which one should be sociomaterial conceptual.